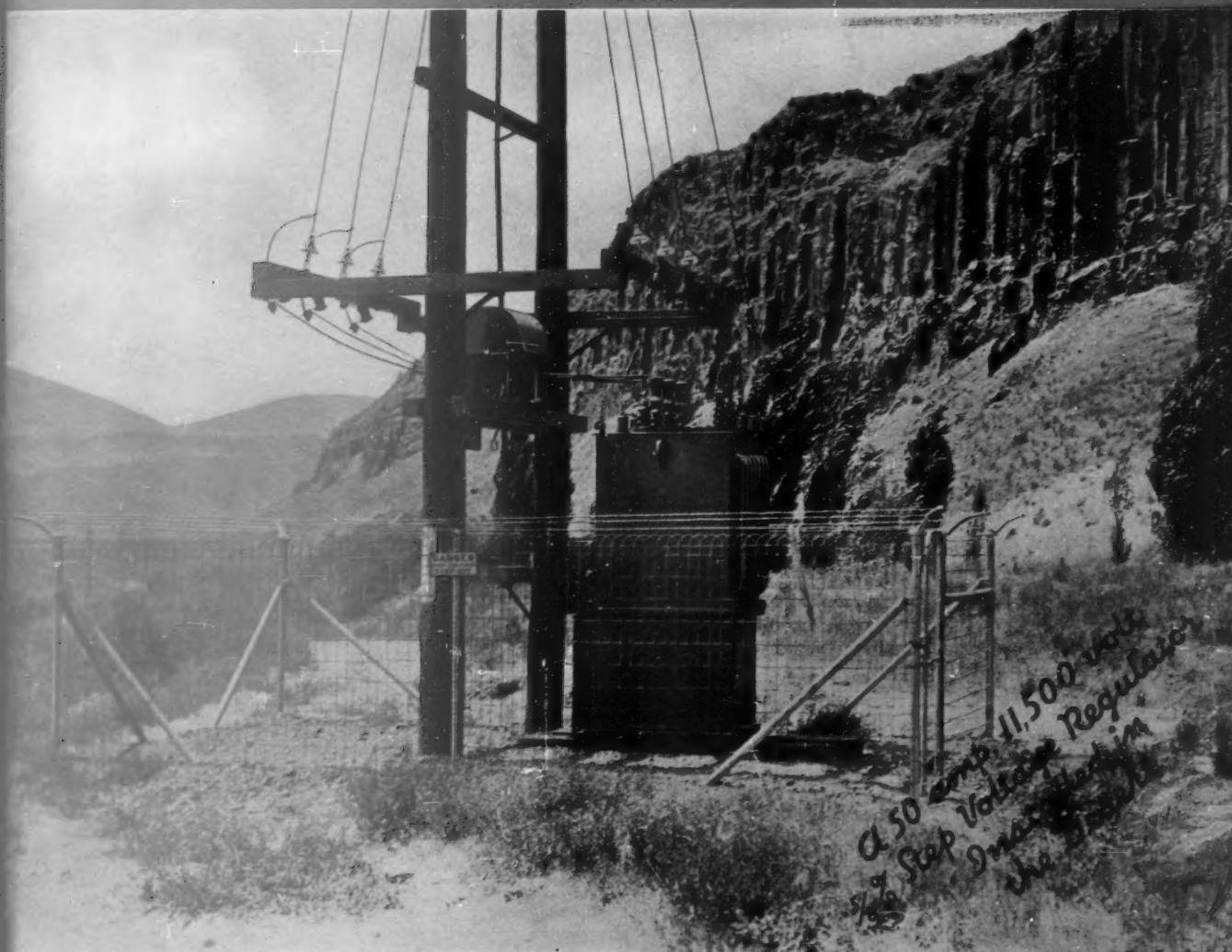


ALLIS-CHALMERS ELECTRICAL Review

Mr. J. J. Greagan,
Birmingham Office.



In This Issue:

Reactive Current

The Why of Boulder Dam

Distribution Transformer Protection

SEPTEMBER
1936

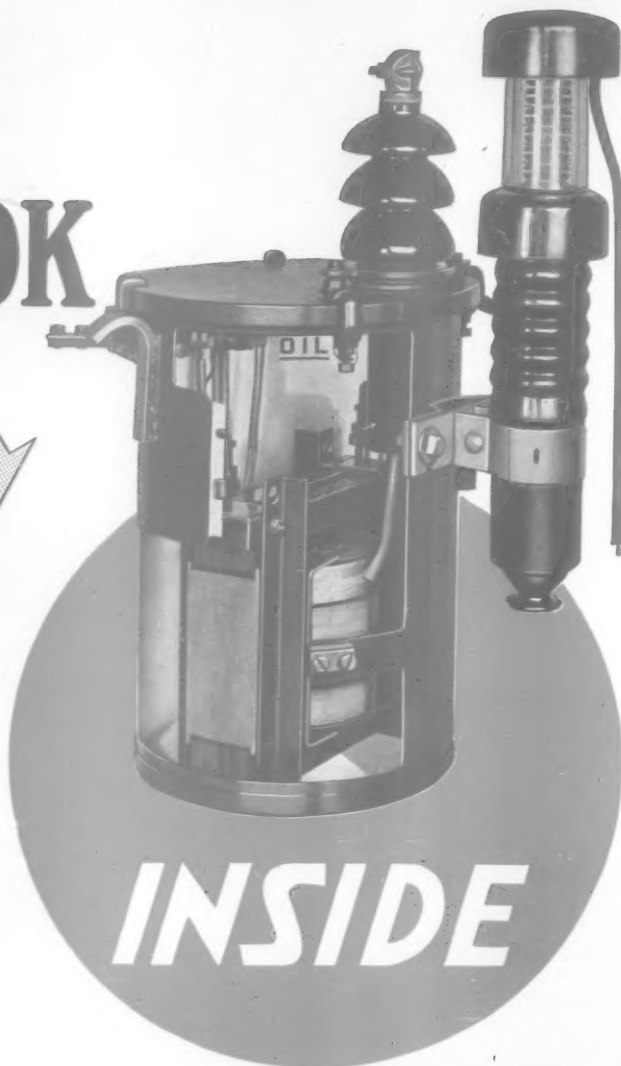
LET'S LOOK



MOST rural line transformers look the same from the outside—but remember, the most important part of a transformer is beneath the surface. And that is where most transformers differ.

Allis-Chalmers Rural Service Transformers feature:

1. Spool Wound High Voltage Coils, separately removable.
2. Coordinated High Voltage Bushing, with extra long shank submerged in oil.
3. Continuous Oil Duct between High and Low Voltage Windings.
4. Circular Resistance Welded Tank. All tanks tested under oil pressure.
5. Integrally Mounted Surge Diverters.



1½ kva, 6900/11,950 high voltage, 115/230 low voltage,
Type HAE High Efficiency Rural Line Transformer.

TRANSFORMER DIVISION
ALLIS-CHALMERS



M I L W A U K E E W I S C O N S I N

SEPTEMBER
1936

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No. 1

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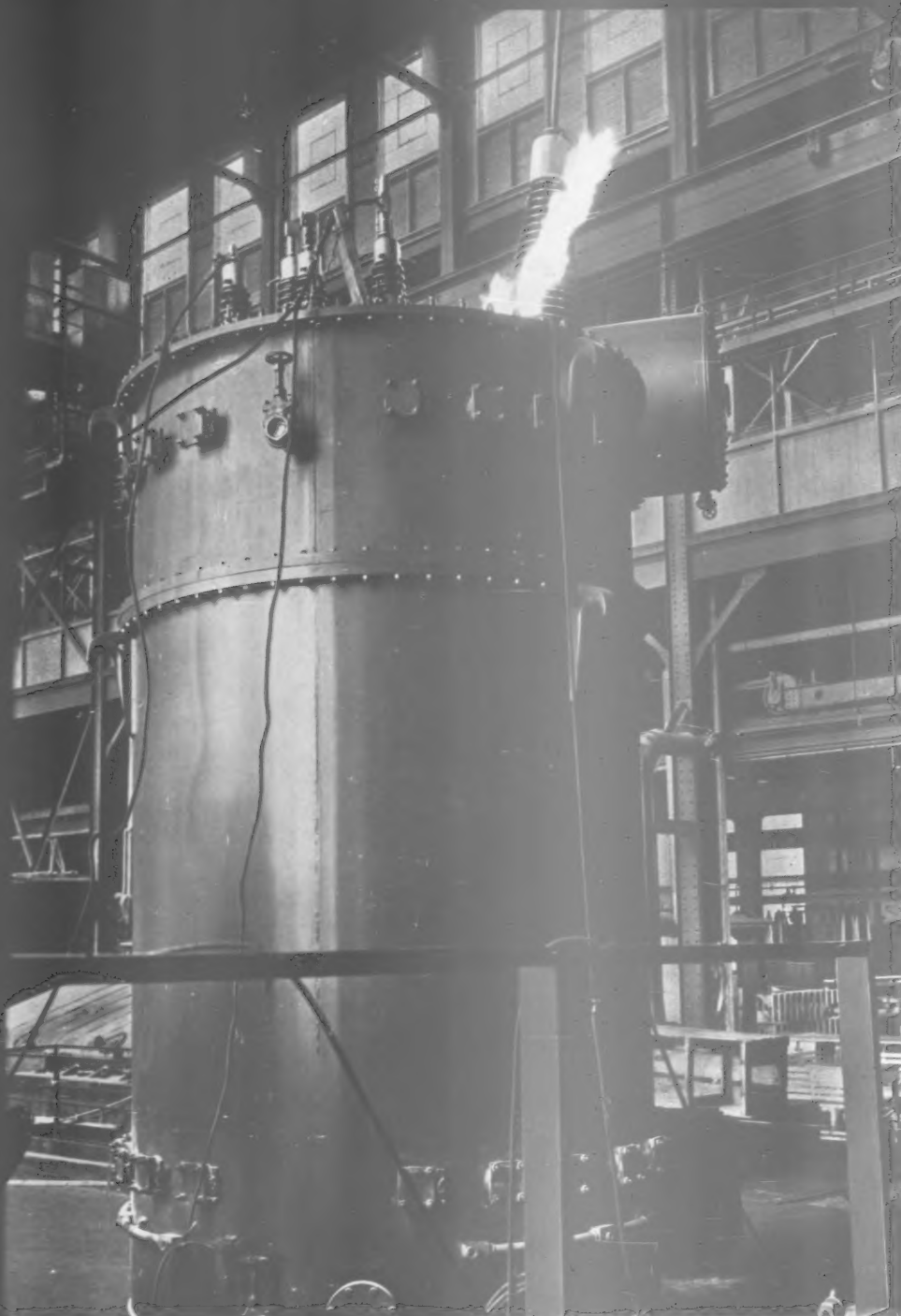
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IMPULSE TEST

Theory of Distribution Transformer Protection

J. B. HODTUM
Development Engineer
Transformer Division
Allis-Chalmers Mfg. Co.

DISTRIBUTION transformers are subjected to two types of disturbances, over-current and over-voltage. The over-current type can be adequately protected against by proper fusing and by proper construction of the secondary mains; the over-voltage type, by lightning arresters, properly inter-connected.

Secondary Faults

Most distribution transformers will safely carry a load 200% of rating for short periods of time. This then fixes the lower limit of the fuse rating. In general, secondaries are of such length that in most cases a two-wire 120-volt fault at the end of the mains will produce 5 times the primary rated current. Thus, the upper limit of the fuse rating is about 5 times the transformer rating. If the 5 times rating is adopted, there may be partial faults that produce less than 5 times rated current, or the secondaries may be so long that 5 times rated current cannot flow. A few transformers may fail from such partial shorts. The number would be so small, however, that it would be economically unsound to provide protection for all units in order to save a few. For the long secondaries, the remedy, of course, is to shorten them. In other words, fusing should be adjusted on the basis of fault currents, rather than attempt to fuse for overload.

This should likewise apply to branch line fuses. Such fuses should not be adjusted by the load connected to the branch, but to the minimum short circuit current of that branch. If such a plan is used, fuse trouble will be greatly reduced and faults will isolate themselves.

Some consideration must likewise be given to the co-ordination of the time current characteristics of the fuses with the tripping circuit at the feeder circuit breaker.

Most fuse manufacturers furnish time current ratings of their fuses. As a typical case we have taken such data from one of the large manufacturer's fuse characteristic curves. The data was expressed in the time required to blow, against the crest current value of a sinusoidal current wave, where the time corresponds to $\frac{1}{2}$ cycle. It can be shown mathematically that for an exponential current wave, the crest value of the current is 83.0% of the sinusoidal value, when the time to reach $\frac{1}{2}$ crest value corresponds to $\frac{1}{2}$ cycle. In other words, the amperes-squared-time value under both curves is identical. There is a difference in that for the sinusoidal current the fuse blows in $\frac{1}{2}$ cycle, while for the exponential current the time becomes infinity.

From this we have prepared Fig. 1. Most lightning surges are less than 40 micro-seconds duration. Therefore, a lightning surge of 40 micro-seconds duration would have decreased to $\frac{1}{2}$ its crest value in 6 micro-seconds and would require a crest current value of 1,520 times its rating, to just blow the fuse. A 10 ampere

How to Fuse Properly for Over-Current . . . Proper Method of Inter-Connection for Over-Voltage

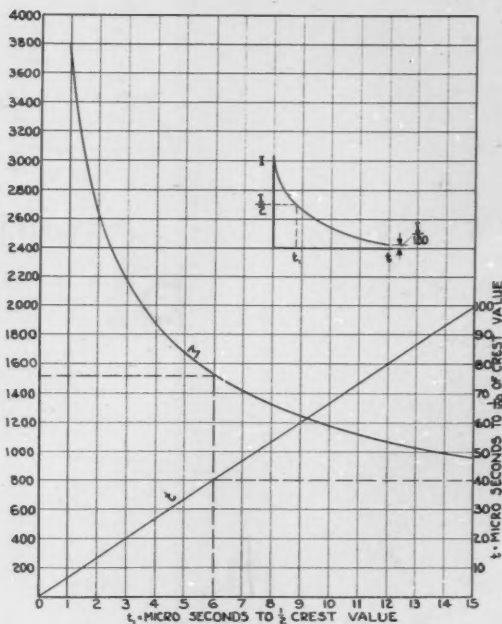


Fig. 1—Surge Current Capacity of Fuse Links

For an exponential current wave where, t_1 = time for wave to decrease to $\frac{1}{2}$ crest value, or, t = time for wave to decrease to $1/100$ crest value, the current, expressed in crest amperes required to blow fuse, is:
 $M \times \text{Fuse Rating (in amps.)}$

EXAMPLE

For a current wave where $t = 40$ from the curve, $t_1 = 6$ and $M = 1520$. If fuse is rated 10 amp the crest current to blow it is:
 $1520 \times 10 = 15,200$ amp.

fuse, for example, would require a crest current of 15,200 amperes to just blow it. From "Electrical Engineering" of December 1935, page 1398, figure 6, an urban transformer installation is subject to less than 15,000 amperes 99.8% of the time, or for a rural installation 99.5%. Thus the percentage of fuse outage for a 10

ampere fuse is of the order of .2% in the city and .5% in the country.

From the standpoint of lightning protection, we find two divergent opinions, both given at the 1936 A. I. E. E. Mid-winter Convention in New York City. One report indicates the effectiveness of the lightning arrester inter-connection depends, among other factors, upon, the arrester ground resistance; the other report, that it is independent of the ground resistance. Both of these papers are correct and we shall try to show how to apply inter-connection to make it independent of the arrester ground resistance.

Voltage distribution throughout the transformer, when subjected to steep wave front voltages, depends upon the electrostatic capacity between the various parts and also upon electromagnetic induction. We shall confine the discussion to the electrostatic conditions.

STANDARD CONNECTION

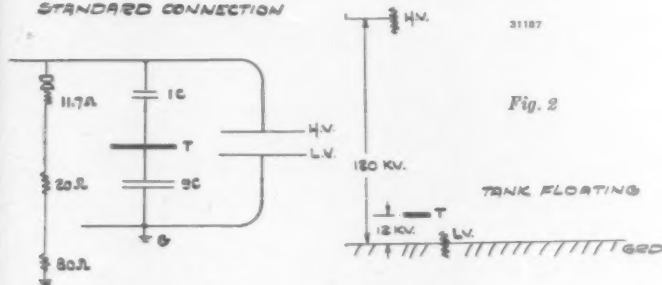


Fig. 2

INTER CONNECTION

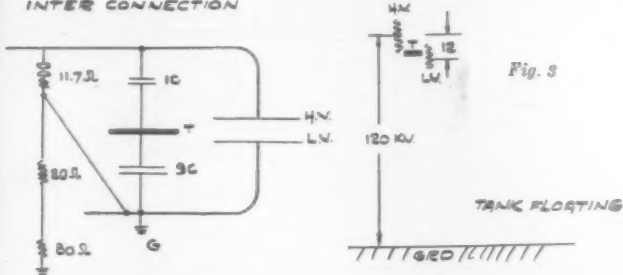


Fig. 3

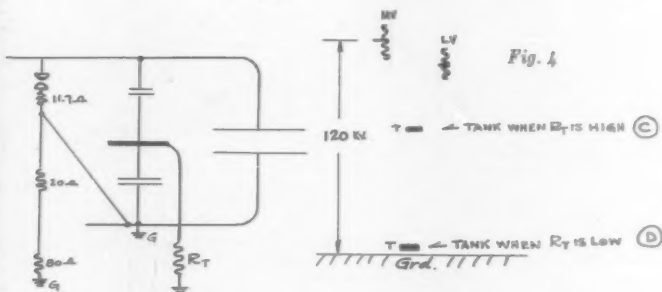


Fig. 4

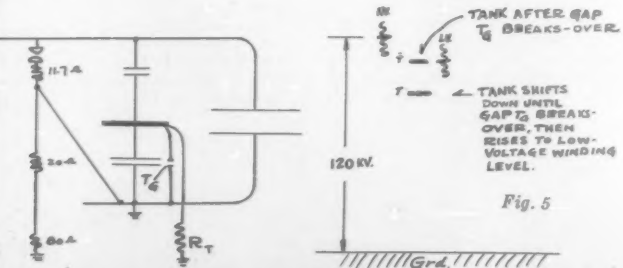


Fig. 5

The transformer consists essentially of three condensers.

- (1) High voltage winding to low voltage winding.
- (2) High voltage winding to case.
- (3) Low voltage winding to case.

The capacity HV winding to LV winding is not important, since it is not large enough to limit the voltage drop across it due to the heavy current discharge. The other two capacities, however, determine the potential of the tank with respect to the windings. In order to determine the tank potential, it is necessary to know the capacity of HV to case, and LV to case. In fact, absolute values are not necessary, but the ratio of the two values is. From a number of tests, it was found that the capacity LV to case is about 9 times that of HV to case. This means that the case, assuming no electrostatic leakage, is above the LV winding by 1/10 of the voltage between HV and LV windings.

As the case is in contact with the pole, which may be damp, the ohmic resistance to ground may be low. Since this voltage is only maintained by the current flowing through the winding capacity to the case, and as this capacity is extremely small, most of the voltage drop appears between case and windings, and the tank assumes a potential close to ground.

It is the variation of this factor, leakage resistance of the tank to ground, that determines whether the effectiveness of the inter-connection is dependent upon ground resistance or whether it is independent of it. If the leakage resistance with the tank to ground is low the effectiveness is increased with low arrester ground resistance. If it is high, it is independent of the arrester ground resistance.

In order to estimate the voltage distribution it is necessary to know the impedance voltage drop of the lightning arrester, at various currents, and the impedance of a single vertical wire (arrester ground lead). For very steep wave fronts, the lead reactance may vary from 1/2 to 2 ohms per foot of wire.

It is now possible to construct a diagram of the transformer and its connection and then by assuming a given current discharge, estimate the voltage between the various parts. The diagram for a non-inter-connected circuit is shown in Fig. 2.

The value 11.7 ohms represents the impedance of a valve-type arrester at 1,000 amperes surge current discharge. The 20 ohms represents the impedance of the ground wire from the arrester to ground. The 80 ohms represents the ground resistance. For the laboratory test the 20 ohms lead reactance and the 80 ohms ground resistance were combined into a single resistance of 100 ohms.

The protection afforded depends upon the arrester ground resistance and the voltages shown are those produced by a surge current of 1,070 amps.

With the Inter-connection, Fig. 3, if the tank leakage is zero (infinite resistance) then the voltages between the various windings are as follows:

- H & L Windings = 11.7 KV.
- H & T Windings = 10.53 KV.
- L & T Windings = 1.17 KV.

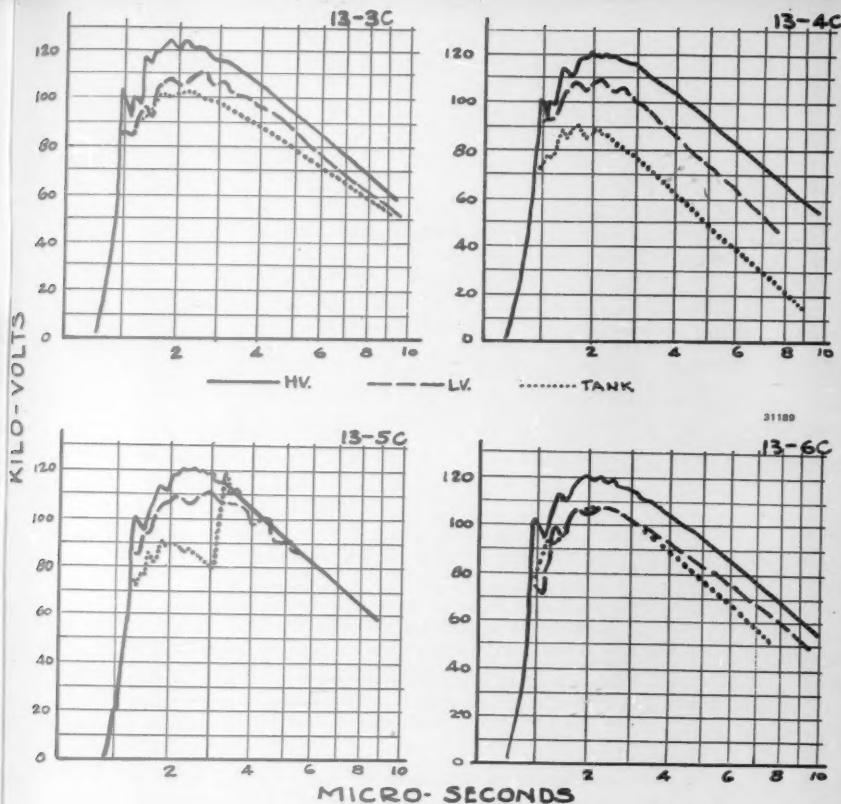
The insulation level of the 2400-volt class transformer is of the order of 70 KV, so the above values are so low that breakdown of windings or bushings could not occur.

Fig. 4 "C," shows the effect of high resistance from tank to ground and instead of assuming a potential between the HV and LV the tank potential falls below them.

Fig. 4 "D," shows the results when the tank leakage is large enough to bring the tank potential close to ground. Then the voltage distribution becomes:

Schematic analyses of inter-connection methods (Figs. 2 to 5).

KILO-VOLTS



H to L — 11.7 KV.
H to T — 119.52 KV.
L to T — 107.82 KV.

Such voltages would either cause a failure of the LV winding to tank, HV winding to tank, or a flashover of the bushings. If the HV bushings flashover, a path is established for power current, and the primary fuses would blow.

Fig. 5 shows the same condition as in Fig. 4 "D" except a gap has been added between the LV winding and tank. Assuming this gap set for breakdown at 15 KV impulse, then as soon as the voltage between tank and LV reaches 15 KV the gap breaks which brings the tank up to the LV potential. Then the voltage distribution becomes:

HV to L — 11.7 KV.
HV to T — 11.7 KV.
LV to T — 0.

With such voltages, nothing within the transformer can flashover, no path is established for power voltage and the only current through the fuse is the surge current.

Oscillograms indicate the various actual voltages corresponding to a steep wave current surge having a crest of approximately 1070 amperes.

Fig. 6 — Tank ungrounded.

Fig. 7 — Tank grounded through 8,000 ohms.

Fig. 8 — Tank grounded through 8,000 ohms and HV bushing gapped down to $1\frac{3}{16}$ ".

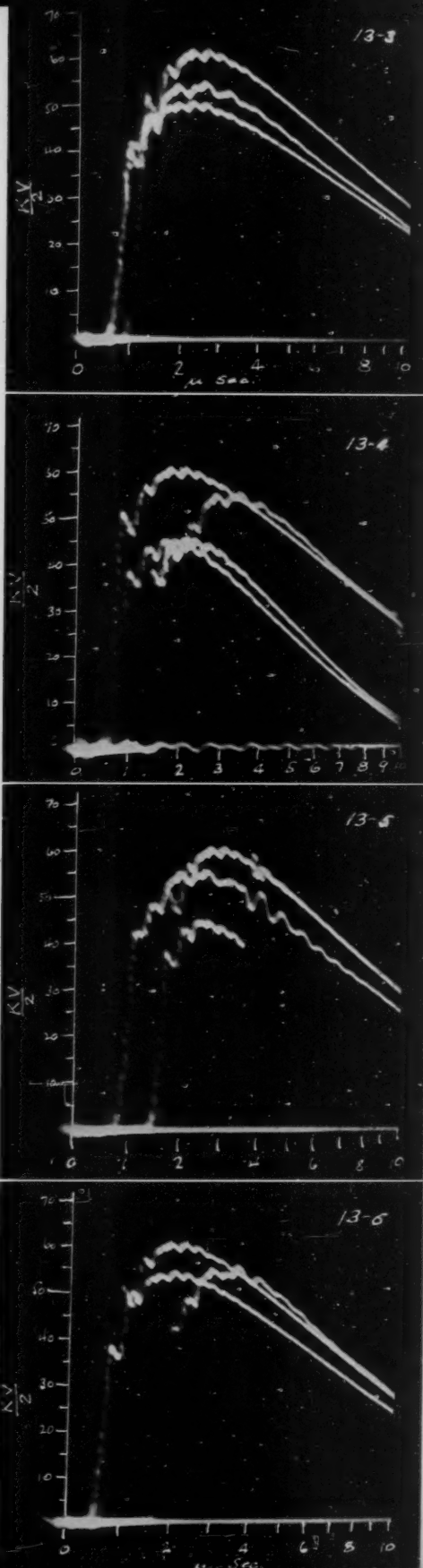
Fig. 9 — Same as Fig. 8 except an additional $\frac{1}{4}$ " gap on low voltage bushing.

Oscillograms of the Figs. 6, 7, 8, 9 replotted to the same time base are shown as Figs. 6A, 7A, 8A, and 9A.

Fig. 6A shows that although the tank is ungrounded, its potential drops slightly below the low voltage winding potential. The voltage difference between the HV and LV winding is the arrester impedance drop.

Above—

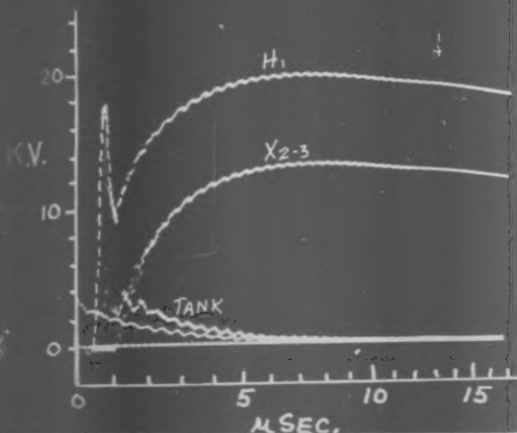
Figs. 6A to 9A (13-3c to 13-6c) oscillograms at right replotted to same time base showing actual voltages of HV, LV and tank during impulse test with four types of inter-connection.



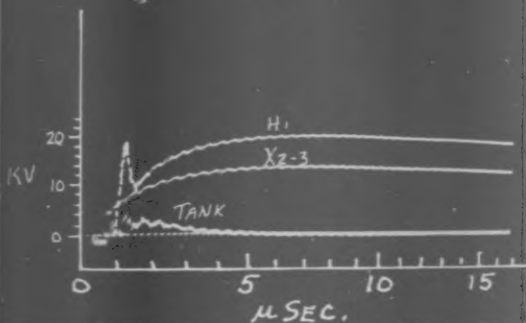
Right—

Figs. 6 to 9, (13-3 to 13-6) original oscillograms of Figs. 6A to 9A.

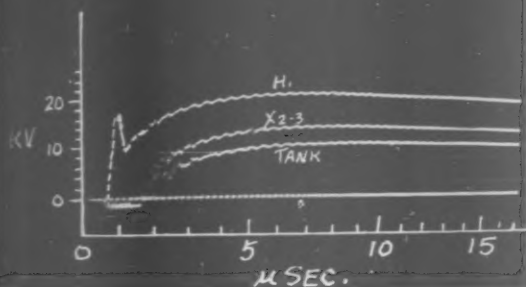
1022-49



1022-50



1022-51



Left—

Figs. 10-12 (1022-49—1022-51) oscillograms of impulse tests with transformer protected as in Fig. 13 (right). Each oscillogram shows same test but effect of different means of measuring voltages.

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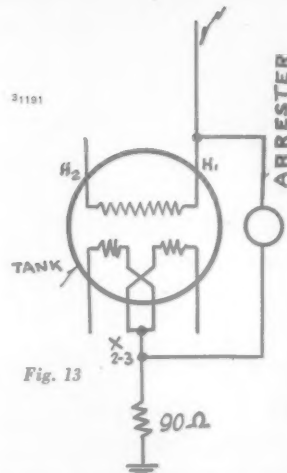


Fig. 13

Fig. 7A includes a leakage path from tank to ground of 8000 ohms. This definitely lowers the tank voltage, and increases the voltage between tank and bushing. Note the voltage across the HV bushings to the tank is approximately 45 KV. Across the LV bushings it is approximately 25 KV. As the bushings in the transformers under test had impulse flashovers of approximately 70 KV and 45 KV respectively, they did not flashover.

In Fig. 8A, a $1\frac{1}{10}$ " gap was placed in parallel with the HV bushings. This was to represent a lead of low impulse strength. When the voltage reached approximately 35 KV between tank and HV, the gap flashed over. In operation this would have been followed by power follow-current resulting in a fuse failure, although the unit is inter-connected.

Fig. 9A shows the same condition as Fig. 8A except there is a $\frac{1}{4}$ " gap in parallel with the LV bushings. Note that the tank and low voltage remain together for approximately 3 micro-seconds. As there is no power current available to maintain the arc, the tank again starts to float away. Note also that at the voltage crest the voltage between the tank and HV bushing is only about 12 KV and increases to approximately 20 KV at 8 micro-seconds. If the tank is solidly connected to the LV, the tank and LV remain together and at 8 micro-seconds the drop across the HV bushings is about 10 KV instead of 20 KV.

Figs. 10, 11, and 12 show tests using the connection shown in Fig. 13. Fig. 10 shows the voltage measured with resistance divider (698 ohms) when the resistance divider grounds the tank. Fig. 11 shows the same as Fig. 10 except voltages are measured with the capacity divider. Fig. 12 shows the results with the resistance divider disconnected and the capacity divider used.

It is our belief that the reduction of fuse outages on inter-connected transformers has not been realized, because the tank leakage brings the tank potential to ground. This causes high voltage to appear at the HV bushings, resulting in power follow currents which in turn blow the fuses.

A number of operators have suggested by gapping the tank to the LV winding, flashovers will increase because of reduced insulation. The reduced insulation, however, causes the LV to flash-over first, thus reducing the voltage over the HV bushings, and thereby preventing flashovers and follow-current. Without flashovers, fuses should not blow.

An interesting check was made with one large power company. The original units purchased by this company had LV bushings of approximately the same flashover value as the high voltage bushings. This was done to reduce the number of kinds of spare stock bushings. These units are blowing fuses. Several years ago this design was changed to coordinated HV and LV bushings, and last year's record indicates that not a single fuse was blown from lightning on such units.

In conclusion, the effectiveness of the lightning arrester inter-connection is increased as the lightning arrester ground is decreased when the tank is ungrounded. It is independent of the ground resistance when the tank is included in the discharge circuit. Therefore, the proper scheme of inter-connection must include the tank in the discharge circuit, either through a gap or directly connected. The direct connection is preferable.

If the voltages produced by surge currents are kept below the flashover value of the HV bushings when properly inter-connected power follow current will not flow and fuses will not blow. The duty of the fuse is, therefore, only to protect against power faults.

THE RUPTOR

A Modern High Efficiency Interrupting Device for Oil Circuit Breakers

C. D. AINSWORTH
Chief Engineer
Condit Electrical Mfg. Corp.

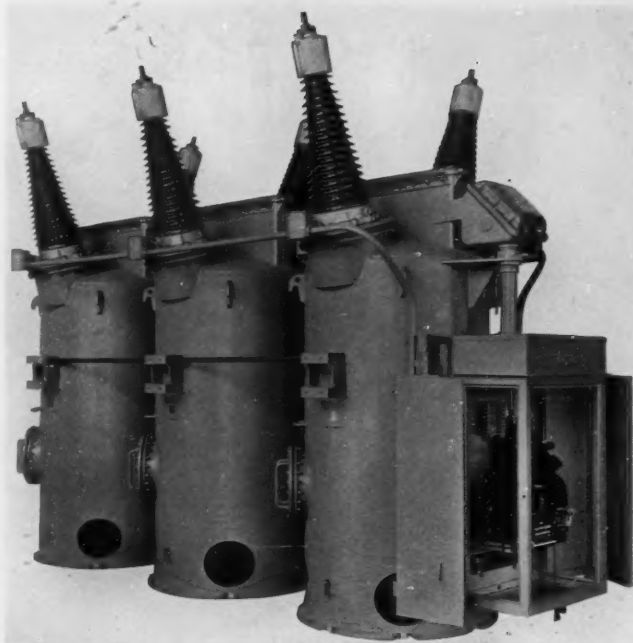


Fig. 1—Type BZO-60-115B 600 amp, 115 kv, 500,000 kva Interrupting Capacity Ruptor Equipped Outdoor Oil Circuit Breaker

WERE a specification to be drawn for an "ideal" oil circuit breaker to fulfill the requirements of the larger systems, it would read essentially as follows:

1. To limit the rate of deterioration of the oil and of the contacts, and to assure low tank pressures and eliminate oil throw, the arc energy per half cycle shall be low and the number of half cycles of arc few.
2. To further reduce the rate of deterioration of the main oil body, the arc-interrupting oil body shall be isolated from the main oil body by an arc enclosing device and the interruption shall take place substantially within the device so that the arc is exposed only to the relatively small volume of oil contained therein.
3. To promote the quick-clearing function of the breaker, there shall be a minimum of time between contact separation and the beginning of effective interrupting action.
4. The arc-interrupting enclosure shall be sufficiently strong and its openings so restricted that it will act as a pressure barrier between the arc source of pressure and the tank in the event of an abnormally severe interruption.
5. The arc-interrupting device shall be simple in principle, construction and adjustment. It shall not be subject to rapid deterioration, and shall be easily accessible for the inspection and maintenance of contacts and readily renewable as a whole or in part.

The Development of the Ruptor

With the specification of the "Ideal" Oil Circuit

Breaker in mind, an intensive program of research and development was initiated to produce an interrupting device for oil circuit breakers to meet these requirements.

As an initial step, twenty-three separate and distinct devices were designed and completely tested. Of this number, two were then selected as the more efficient devices and as those better adapted to application throughout the range of voltages and interrupting capacities. These two devices were checked, revamped and improved and then more exhaustively tested until it was possible to select the better of the two—thence, the Ruptor—The one selected from the twenty-three.

The process of development of a modern interrupting device is a long and arduous one. After the basic idea and the experimental model must come the research tests to determine the fundamental laws applying to the new principle. The device is alternately revised and tested, removing objectionable characteristics, adding new features, simplifying and correcting until finally sufficient information is available to make a finished design of the device for one class of service. At any time in the process, new theories and test results may, and often do, change the entire trend of the investigation and result in the discarding of the original device or version for a superior one. Then must come the application tests in which the mechanical and electrical requirements of each breaker are reconciled with the necessary size and characteristics of the interrupting device. Here new ideas must be incorporated in surmounting new difficulties, before the application can be completed throughout the necessary range of voltages and interrupting capacities. Such a process was the development and application of the Ruptor.

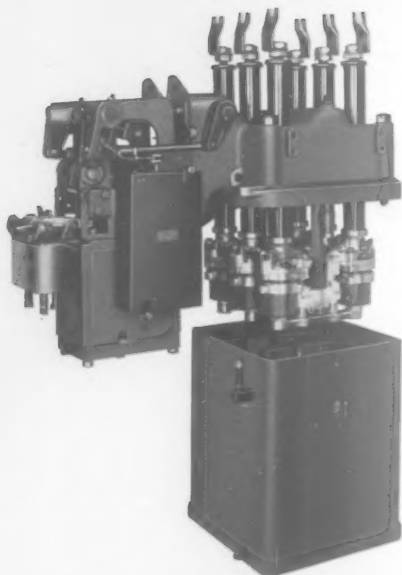


Fig. 2—Type DZ-40, 600 amp, 15 kv, 100,000 kva Interrupting Capacity Ruptor Equipped Indoor Oil Circuit Breaker

Testing

With the passing of the old 2-OCO two-minute standard duty cycle and the type of breaker which it fostered, passed the old order of circuit breaker testing. For the proof testing of modern high efficiency breakers, a few random shots on some power distribution system, at such place and under such condition as will not impair service or endanger equipment, may be indicative, but they are not conclusive. For the research necessary to develop these breakers, such means are of little value.

It is upon the modern power testing laboratory that the manufacturer must now depend largely for proof-testing of his high efficiency breakers and upon which he must depend entirely for their development.

The extent to which the laboratory is utilized is shown by one phase of the Ruptor development program. For the 15 kv, 500,000 kva device alone upwards of 1000 tests were required before the design and application of the device was considered satisfactory. Thereafter, a much greater number of proof-tests were

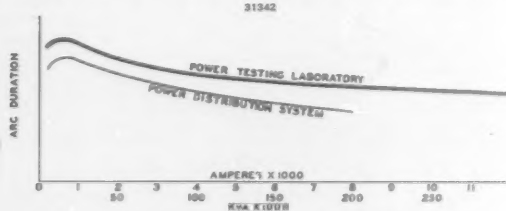
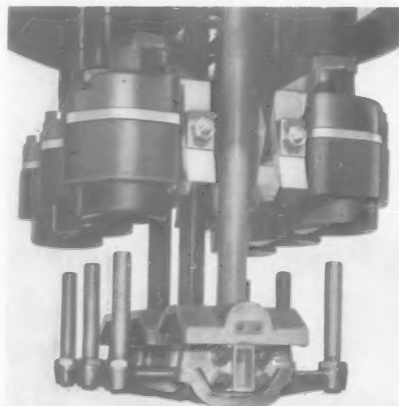
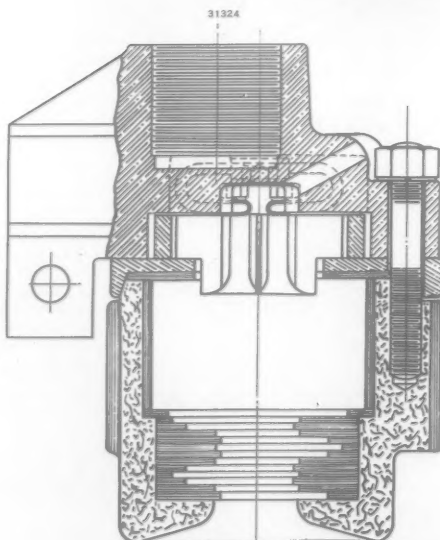


Fig. 3—Comparative Severity of Interrupting Duty—Distribution System Versus Short Circuit Laboratory

A comparison of the severity of system and laboratory short circuits as measured by comparative performance of the same breaker exhaustively tested under the two conditions.

Fig. 4—Ruptor, 250,000-kva Interrupting Capacity

- a. (Top)—External View.
- b. (Center)—Section.
- c. (Bottom) — Applied to Type DZ-100 2000 amp, 15 kv, 250,000 kva Interrupting Capacity Indoor Station Type Oil Circuit Breaker.



made upon Ruptor-equipped breakers—both old types and new—to determine the correctness of application, efficiency of interruption and margin of safety.

Obviously a laboratory for such extensive development programs must be especially designed for the strenuous duty, complete with every facility for the purpose and operated by a carefully selected and trained staff under the direction of experts.

Doubt has been expressed at times as to the ability of the power testing laboratory to reproduce short-circuit conditions comparable to those of the present-day high power distribution system. In other words, the ability to subject a circuit breaker to short circuits as severe as those encountered on the more difficult applications.

Actually, the converse has been found to be almost universally true. The laboratory can produce short-circuit conditions, the severity of which can only be equalled at a few points and under very unusual circumstances on present-day distribution systems. The rate of rise of recovery voltage, which is recognized as the major index of interruption severity, can be readily controlled and can be made as great as may be obtained under any operating condition.

In a number of instances, the relative severity of field and laboratory tests has been so demonstrated as to remove any reasonable doubt. Breakers have been tested so extensively at particular points in distribution systems that the record of their performance became in each case a record of the system conditions. A comparison of these records with those of the same or like breakers tested in the laboratory must then be a reasonably accurate index to the relative severity of the respective system and laboratory short-circuit conditions.

A comparison of the severity of system and laboratory short circuits as measured by such comparative breaker performance is shown in Fig. 3 in terms of arc duration.

It is within the scope of the laboratory to produce, through the medium of excessive rises and rates of rise of recovery voltage, short circuit conditions even more severe than those indicated. The advantages of such scope in testing are apparent.

Characteristics of the Ruptor

Fundamentally, the Ruptor is an arc-enclosing device for oil circuit breakers, designed to so limit the arc energy of interruption and to so control the remnant energy that contact burning, oil deterioration, pressure and oil throw are reduced to a minimum.

A typical Ruptor construction and application are illustrated by Fig. 4, a, b, c, which show the 250,000 kva, 15 kv Ruptor applied to the type DZ-100, 2000 amp oil circuit breaker. The ready accessibility for inspection of contacts and Ruptor parts or replacement of contacts is apparent.

The Ruptor is so arranged that the arc is drawn in an oil reservoir in the upper portion of the device. The moving contact continues to move downward through a restricted passage and finally into the main body of insulating oil.

During the initial movement of the contact tip through the oil reservoir pressure is generated in the chamber. The conformation of the restricted passage so controls the size and form of the arc as it is extended into this passage that recovery of the dielectric strength is inherently rapid. Hence, it is only necessary that a relatively small quantity of oil at low pressure be impelled from the reservoir into the passage to complete dielectric recovery and prevent reignition. To generate this low pressure a low energy arc of short duration is sufficient and it has been possible as a result to make the oil reservoir relatively shallow which minimizes the time between contact separation and the beginning of effective interruption.

At high currents, where the arc energy is greatest, interruption invariably occurs at or near the junction

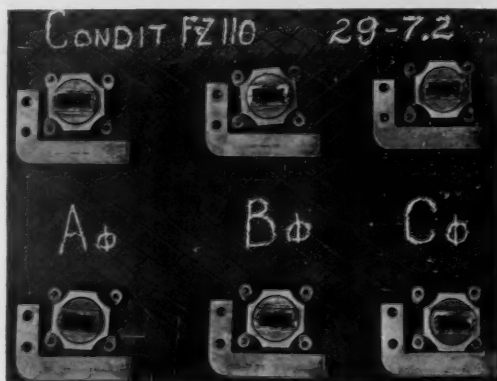
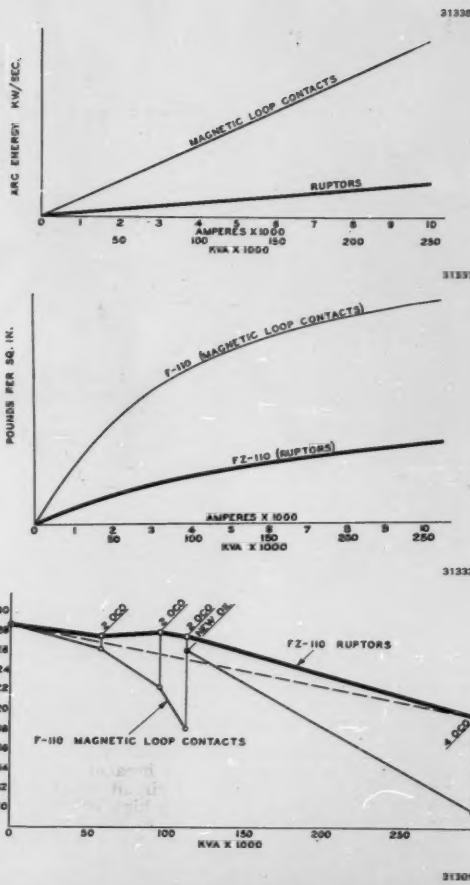
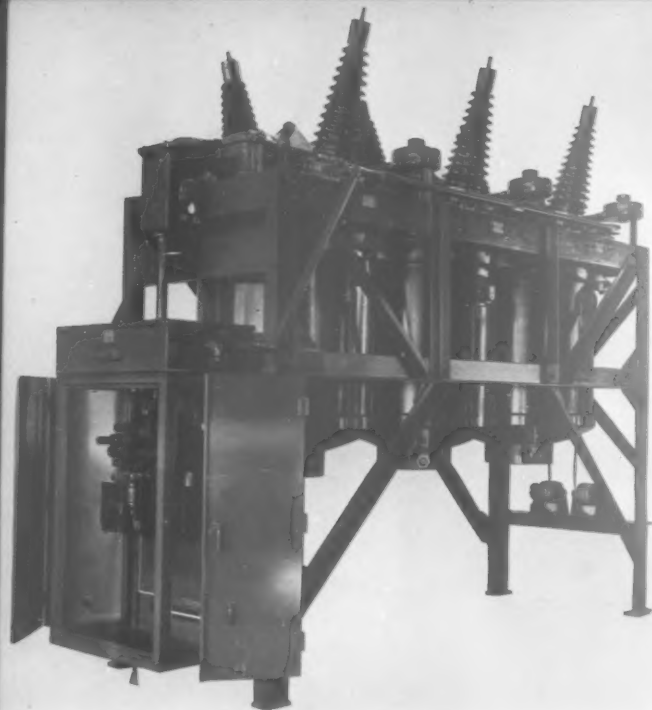


Fig. 5—Interrupting Performance—Plain Break Versus Ruptors

Data taken on an obsolete 250,000 kva tank-per-pole breaker as originally built with open break contacts and equipped with Ruptors. From top to bottom: (a) Arc energy; (b) Tank pressure; (c) Rate of oil deterioration on a typical series of interruptions; (d) Limited contact burning of Ruptor contacts after the series of interruptions.



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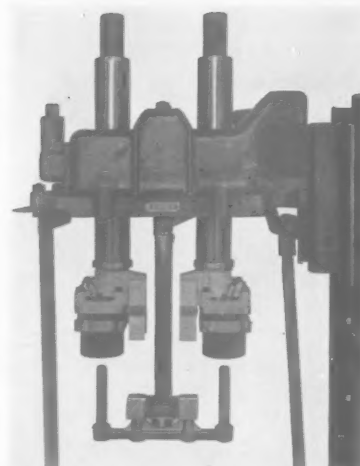
(Left) Fig. 6—Type FZO-50-69D, 600 amp, 69 kv, 1,000,000 kva Interrupting Capacity Ruptor-Equipped Outdoor Oil Circuit Breaker

of oil reservoir and restricted passage, and, therefore, farthest away from the main oil body of the breaker. At low currents it occurs near the outlet of the passage. In all cases, however, the arc is extinguished a sufficient distance within the passage to effect that degree of isolation necessary to the optimum reduction of oil deterioration.

The degree of the limitation and control of arc energy exerted by the Ruptor, and the resulting effect upon arc duration, oil deterioration and pressure are probably best shown by the laboratory test records of the smallest of the so-called "high power" indoor breakers. This breaker has a voltage rating at 15 kv and an interrupting capacity rating of 250,000 kva and is of the unit pole type. As it is designed primarily for applications requiring relatively high interrupting capacity in limited cell space, it is provided with elliptical tanks. Fig. 5, a and b, show a graphic comparison of the arc energy and tank pressure respectively between plain break and Ruptor contacts in this breaker. Fig. 5 c shows graphically the extremely low rate of oil deterioration in this breaker equipped with Ruptors—during a typical series of interrupting tests. Fig. 5 d shows the limited extent of the contact burning on this series of tests. That the life of these contacts is equivalent to several such duty cycles is apparent.

The physical limitations imposed upon the Ruptors by the smaller breakers decrease and disappear as breaker sizes increase with increasing interrupting capacity and voltage ratings, and the efficiency of the Ruptors increases accordingly. The total arc energy declines to orders considerably below 1 kw-sec. per each 1000 kva interrupted, and the rate of oil deterioration consequently becomes extremely low. Tank pressures from the interruption of 500,000 kva or more are too low to make a legible record.

The benefits of high efficiency operation are not confined to new breakers. Actually the curves of oil deterioration of the types F-110 and FZ-110 shown in Fig. 5 c are from tests made on one breaker, the lower curve being that of the obsolescent breaker and the upper curve that obtained after Ruptors had replaced the original plain break contacts. Ruptor installations



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Fig. 7—Type FZ-206, 2000 amp, 15 kv, 150,000 kva Interrupting Capacity Ruptor-Equipped Indoor Station Type Oil Circuit Breaker

in old breakers throughout the range of interrupting capacities and operating voltages have been made and have proven their worth. So during the period of diminished engineering budgets and of expenditures pared to emergencies and necessities, the Ruptor proved the economical solution of the problem of the old breaker on troublesome lines.

Ruptors are now commercially used on breakers of 100,000 kva interrupting capacity and above and 15 kv nominal operating voltage and above.

Circular Coil Shell Type Construction

For Large and High Voltage Power Transformers

L. H. HILL

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IT IS AN established fact that, for any given rating, a transformer may usually be constructed either shell type or core type; with rectangular coils or with circular coils; with concentric windings or interleaved windings. Even though it may be possible to build certain classes of transformers with almost any form of construction, there is, however, usually one form that has advantages over others for the given application. The circular coil shell type transformer has definite advantages for large and high voltage power transformers.

The circular coil shell type transformer is made up of interleaved circular disc coils arranged in the vertical plane and with a double magnetic circuit as in Fig. 1. Circular coils are unexcelled for power transformers. There are no short radii requiring pounding on the conductors to bring them into line, and the coil winds up with uniform tension. The absence of sharp corners gives ideal conditions for minimum electrostatic stress. The shell type of construction permits the use of solid insulation material combined with oil ducts between coils in the same group without impeding oil circulation. This combination is far more effective than straight oil distance in obtaining high impulse strength.

The circular coil shell type construction, because of the proportions of the various capacitances involved due to the inherent nature of the construction, may be readily designed to give excellent voltage distribution under impulse conditions and include all the advantages of electrostatic shielding without introducing additional potential hazards.

Furthermore, the circular coil shell type design lends itself to simple strong mechanical bracing of the windings with the winding approximately 80% encased in steel.

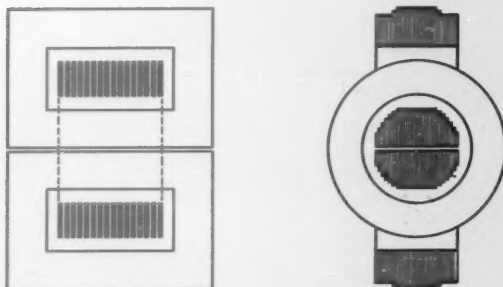


Fig. 1—Circular Coil Shell Type Construction

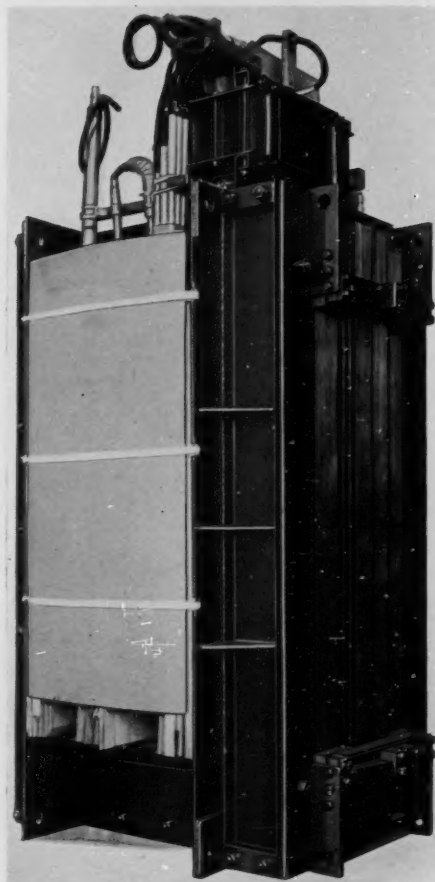


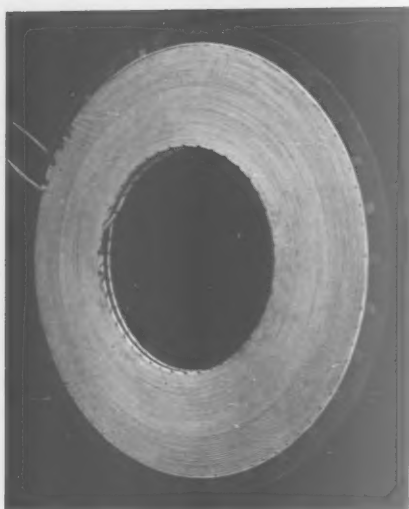
Fig. 2—Core and Coils for 20,000 kva, 32,000 Volt Transformer

Construction

Fig. 2 represents the core and coils of a circular coil shell type transformer with the windings and core arranged as in the schematic diagram of Fig. 1. The full cross section of the magnetic circuit passes through the center of the coils and then divides and returns over the top and bottom of the coils in two opposite directions. All coils are circular and are mounted in the vertical plane.

The windings are all of the disc type and are generally wound double so there are no connections on the inside. Fig. 3 shows a typical double coil.

The conductor insulation consists of spirally wound 2 mil cable paper with several layers, depending on the



**Fig. 3—Double Coil for Circular Coil Shell
Type Transformer**

line voltage, applied three-quarters overlapped to provide not only high insulation strength but insulation capable of withstanding severe mechanical abuse.

Fig. 4 shows a coil being wound and the conductor insulation being applied at the same time. Fig. 5 shows the conductor insulation in detail.

The high voltage and low voltage disc coils are as-



Fig. 5—Conductor Insulation Showing Three-Quarter Lap

sembled in interleaved groups where necessary to obtain the proper amount of inherent reactance. The coils are assembled on a foundation tube that fits over the cruciform section of the core and has a length equal to the opening in the core. The insulation between coil groups to ground is made up of a series of angle collars interleaved with tubes and washers as indicated in Fig. 6. Channel-shaped pieces of insulation interleaved between the washers at the four outer sides complete the insulation at these points.

The coils in a given group are insulated from each other by pressboard washers. All coils have an oil duct on one or both sides. The ducts are maintained by pressboard spacers attached to the pressboard sheet next to the insulating washers as shown in Fig. 7. These are arranged so as to support the windings without affecting the flow of oil to the innermost parts of the windings. Fig. 8 shows a model made up to actually observe the oil circulation obtained with this construction. The excellent circulation of oil is evident.

Performance Under Impulse Conditions

When operating at normal frequency under steady-state conditions, the voltage across the windings of a high voltage power transformer is uniformly distributed. That is, if we assume one end of the high volt-



Fig. 4—Winding Circular Coils

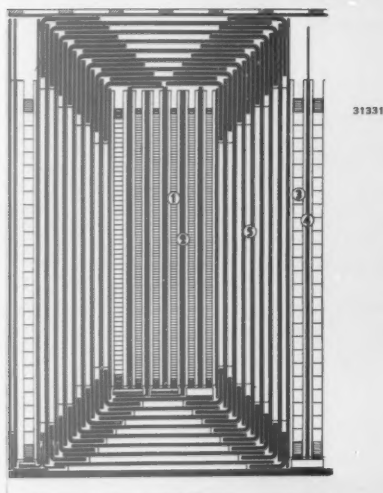


Fig. 6—Arrangement of Coils and Insulation
(1) High Voltage Coil; (2) Solid Insulation Between H. V. Coils;
(3) Low Voltage Coil; (4) Solid Insulation Between L. V. Coils;
(5) Solid Insulation Between Windings and to Ground.

age winding, for example, solidly grounded, the voltage at the grounded end is zero; the voltage at the line end is 100% and the voltage at the middle is 50%. This is shown graphically in Curve A of Fig. 9.

Under impulse conditions, or when a voltage surge strikes a transformer winding, the voltage may or may not distribute uniformly over the winding. For example, it is possible for the voltage to distribute itself as in

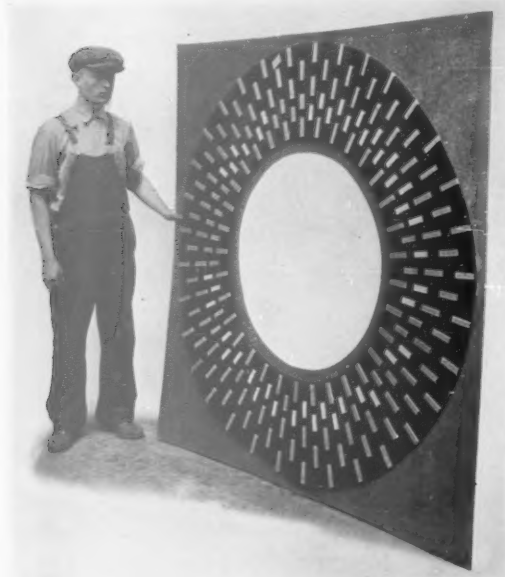


Fig. 7—Showing Spacers for Supporting Individual Conductors

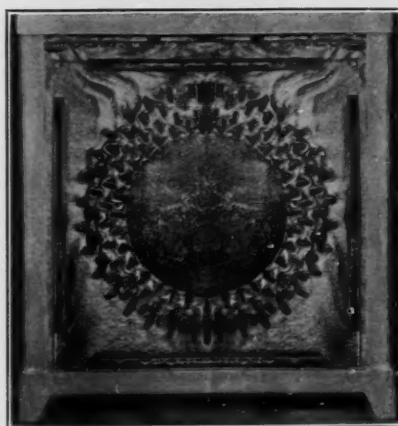


Fig. 8—Model Showing Oil Circulation Between Spacers

Curve B of Fig. 9. It will be noted in this case that 95% of the applied voltage is impressed across but 5% of the winding, which gives 95 divided by 5 or 19 times the voltage stress that would be obtained with uniform voltage distribution.

The reason for this possible poor voltage distribution under impulse conditions may be analyzed in simple terms by considering the electric and dielectric circuits of the transformer. In Fig. 10 "X" represents the inductance of the transformer and C_s groups of lumped

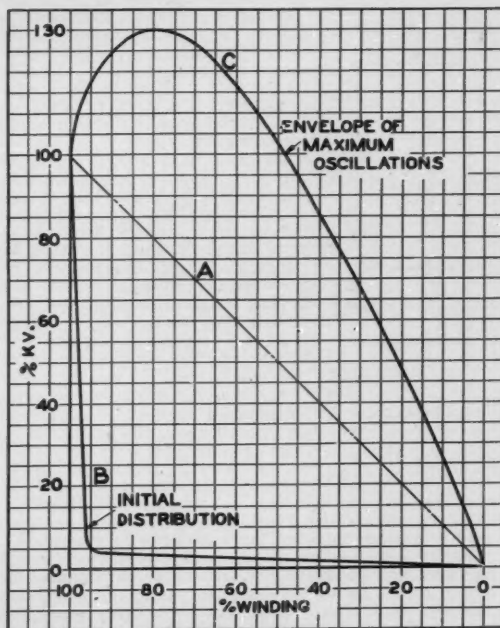


Fig. 9

series capacitance to represent the capacitance between coils. C_s represents shunt capacitance to group which may be from coils to core, end frames, or tank. In an actual transformer the series capacitances are not necessarily equal, and naturally the ground capacitances are not all equal.

Under operating conditions at normal frequency the effect of series and ground capacitances is negligible, because their ohmic value of capacitance reactance is inversely proportional to frequency, and at 60 cycles, for example, they are very high, and therefore, practically no current flows. Under impulse conditions, however, the effect of series and ground capacitance is all important. The impulse of a steep front wave which rises to a maximum very rapidly, for example, in less than $1/1,000,000$ of a second, has the same effect as the first part of a high-frequency wave. Since the ohmic capacitance reactance is inversely proportional to frequency, the series and ground capacitance reactances become very small, and since the inductive reactance of the winding itself increases directly with frequency, the inductive reactance of the windings becomes very high. In fact, this inductive reactance becomes so high that practically all the initial impulse current passes through the dielectric circuit instead of through the electric circuit.

In other words, the circuit of the transformer at the time of a voltage impulse striking it may be considered as in Fig. 11. It may be shown mathematically that the way the voltage distributes across the winding at the first instant depends on the magnitude of the various capacitances, and is largely dependent on the ratio of series to ground capacitance. The greater the series capacitance with respect to the ground capacitance the more uniform will be the voltage distribution across the windings.

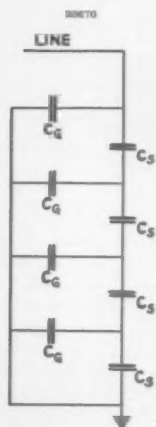


Fig. 11

If Curve B of Fig. 9 represents the initial voltage distribution and Curve A represents the voltage distribution after steady-state conditions, it is evident that oscillations about the final condition will result, and Curve C represents the envelope of voltages which may appear due to oscillations. Obviously the less deviation of Curve B from Curve A the less the magnitude of the oscillations which will occur.

Since the ratio of series to ground capacitance affects the initial voltage distribution, the factors in design which affect these capacitances must be considered. In the high voltage core type of design the high voltage winding is made up of a relatively large number of small coils having relatively small capacity between coils but large capacity to ground. The capacity between two plates is directly proportional to the area and inversely proportional to the distance between them. In order to secure reasonable proportions the core type transformer requires a large number of small coils giving a small area between coils and large area to ground and the low voltage winding, which gives low series capacity and comparatively high ca-

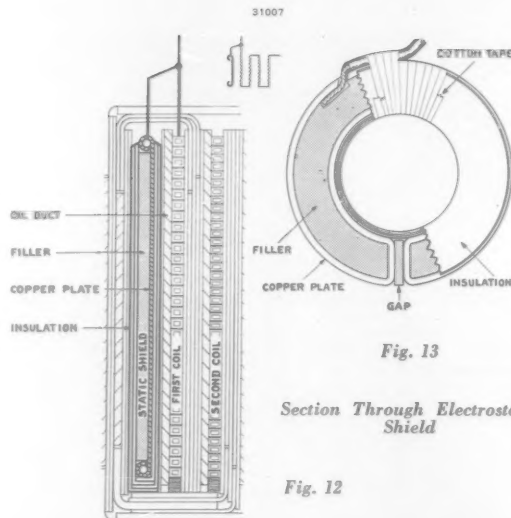


Fig. 13

Section Through Electrostatic Shield

Fig. 12

capacity to ground.

In the shell form of design there are a relatively fewer number of coils of large area so the series capacity is much larger with respect to the ground capacity, and hence the initial voltage distribution is better.

The use of a small number of coils of large area is of course possible in the shell form not only because the proportions of core and coils make this possible, but also because solid insulation may be introduced between the coils in the shell design without affecting oil circulation, whereas in the core type design this is not possible without affecting oil circulation.

In order to improve the voltage distribution across the first coil of circular coil shell type transformers an electrostatic shield is introduced as in Fig. 12. If the shield were not used, the impulse current to pass from the outside turn of the first coil to the inside turn must pass through all of the capacities between turns in series, which would give high capacitance reactance and hence high voltage drop. This explains the reason for

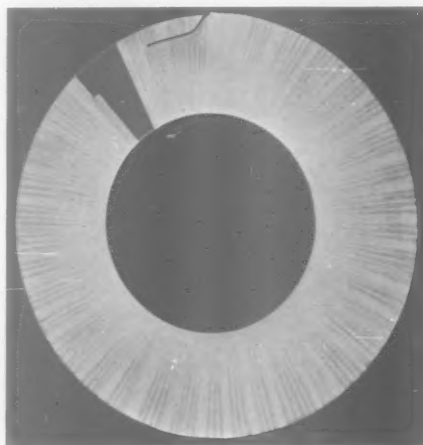


Fig. 14—Electrostatic Shield

"padding" the end turns of transformers which have been built without such shields. The use of the electrostatic shield spreads the line potential uniformly across the first coil since the capacity per unit area of all parts of the shield to the first coil is the same and of comparatively low value. The electrostatic shield is built up of a flat copper plate insulated and installed the same as any other coil in the transformer and hence does not introduce additional potential hazards, affect oil circulation, or otherwise complicate the transformer. Even though the voltage stress across the end turns is reduced by the use of this shield, the insulation on the end turns of the winding is "padded" with the same amount of insulation which has been found satisfactory from service experience without shields.

A section through the electrostatic shield and also a typical arrangement of end coils, major insulation, and electrostatic shield is shown in detail in Fig. 12. The copper plate of the static shield consists of 30 to 40

mils thick hard rolled copper with the inside as well as the outside diameter folded around a copper rod. A gap in the copper plate is provided as in Fig. 13 in order to avoid a short-circuited turn. The amount of insulation on the shield is determined by the voltage across the end coil. This insulation is box-like in form and

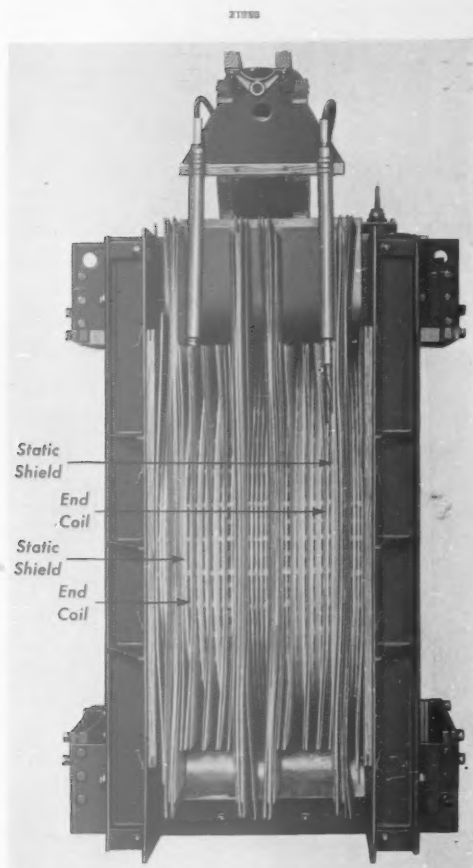


Fig. 15—Core and Coils with Insulation to Tank Removed

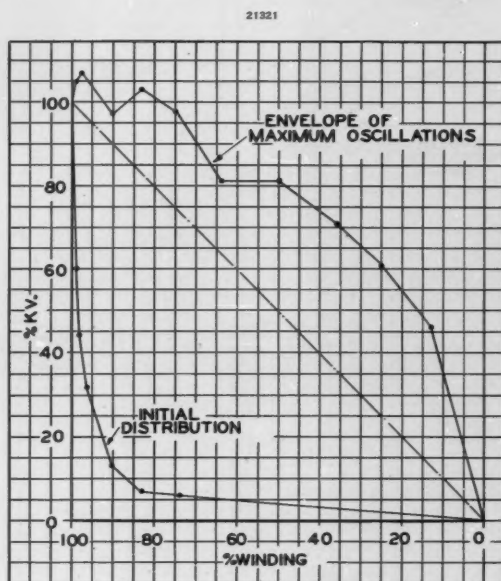


Fig. 16

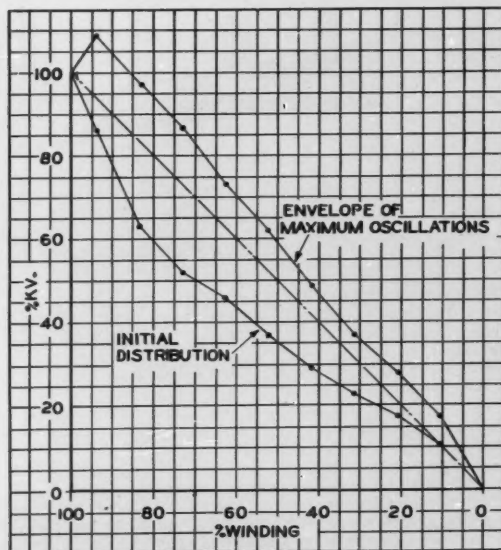


Fig. 17

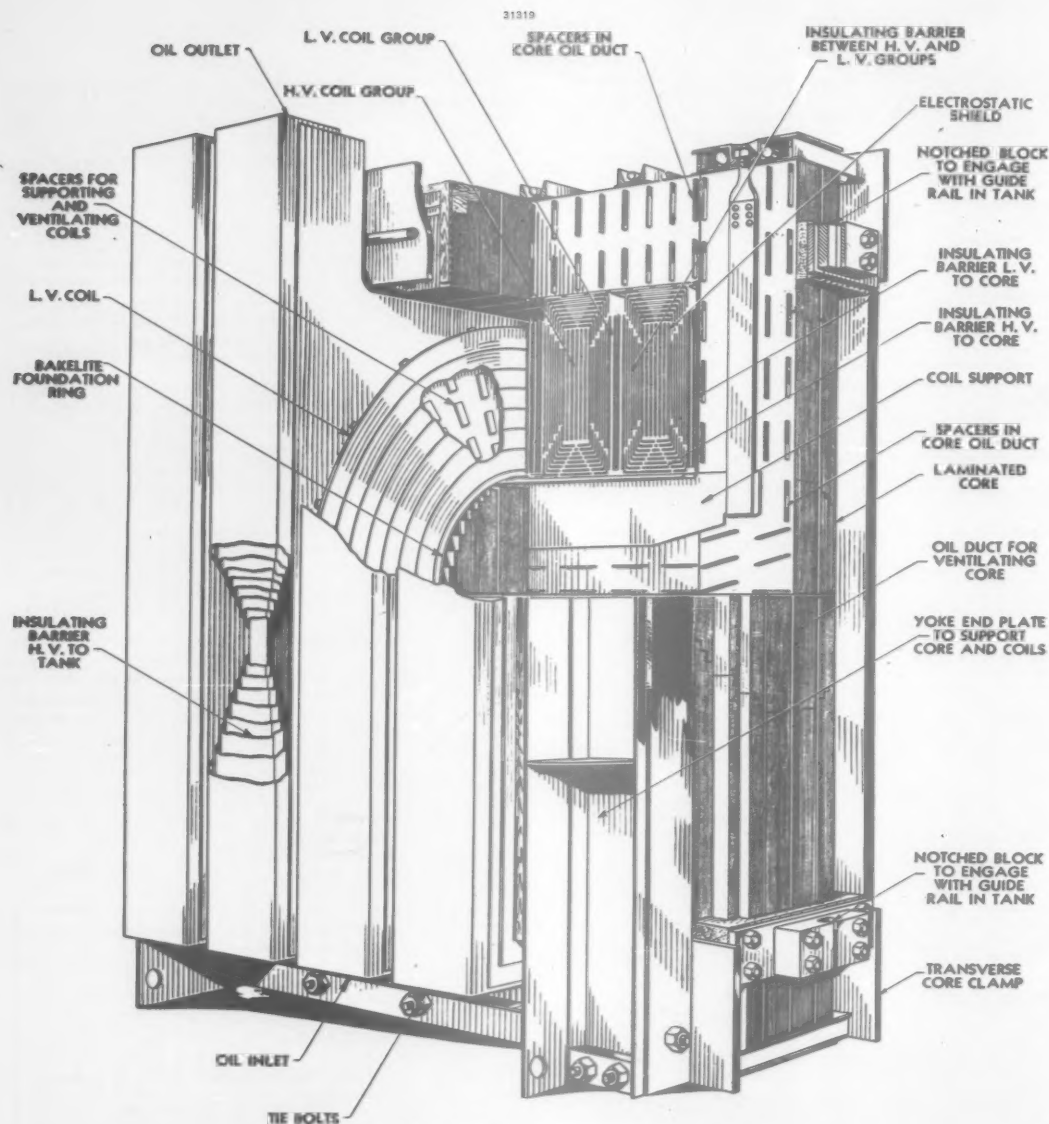


Fig. 18—Circular Coil Shell Type Transformer Construction

built up of segments of 10 mil fullerboard arranged with all joints staggered. A varnished cloth covered cable is brazed to the shield opposite the gap shown and provides a connection to the finish of the end coil. The complete shield is shown in Fig. 14, and Fig. 15 shows its location in the transformer.

Fig. 16 shows the actual voltage distribution curves taken on a core type transformer and Fig. 17 on a shell type.

For low voltage applications the relatively poor voltage distribution in a core type transformer is of comparatively little importance, because the windings can be easily insulated to withstand the conditions imposed. In the case of high voltage transformers, as for example 110,000 volts and above, it is essential that the voltage distribution should approximate a straight line. To

improve the voltage distribution in high voltage core type transformers additional electrostatic capacity (called "shields") is sometimes added. This has the effect of increasing the series capacity with respect to the shunt capacity to ground.

In other words, a point well down in the winding, which without "shields" would be well below the desired level of potential, is brought electrostatically closer to the line potential by bringing a plate connected to the line up close to it.

A comparison of the mechanical details of the means for accomplishing the desired result in both the core and shell type transformers will show the relative difficulty in obtaining good voltage distribution in the two cases. An idea of the simplicity of the means required for the shell type may be obtained from Fig. 12 and

Fig. 2. The means required for the core type require metal shields connected to the line, as shown schematically in Fig. 19, but placed close to parts of the winding at a considerable electrical distance from the line. Subdivision of the shields is required to prevent obstruction of the cooling ducts, but such subdivision increases the difficulty of insulating the shields from the turns of the winding.

In the design of circular coil shell type high voltage power transformers the electrostatic capacities of the various parts may be readily calculated and the initial voltage distribution curve plotted. To facilitate this otherwise tedious calculation, a calculating board has been built. Resistors in this board, of quantitative values inversely proportional to the various capacitances, are set up, and by applying direct current potential in place of the surge voltage, the voltage at any point in the transformer can be read with an ordinary voltmeter. From these data, the initial distribution curve may be plotted. The effect of different coil groupings or different proportions is easily observed. Having obtained the best arrangement of dielectric circuit, keeping other important characteristics in mind, it simply remains to design the insulation of proper amount to meet the known requirements. Actual tests in the impulse laboratory show that initial distribution curves can be estimated within 5% tolerance.

Mechanical Structure

The bracing and supporting of the windings, coils,

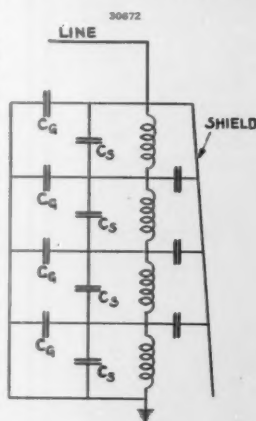


Fig. 19

and leads of the transformer must be sufficient to withstand repeated short-circuit at either set of terminals with rated voltage maintained at the other set of terminals provided the duration of this condition is not such as to cause injurious heating. In the circular coil shell type construction the coil structure is wedged tight around the central tube to prevent radial movement, and the complete winding assembly is clamped together by means of through bolts between the structural steel members of the core end frame in order to prevent axial movement of the coils.

The leads from the coils, taps, etc., to the terminal boards and tap changers are supported in machine-wound tubing. This results in rigid mechanical support of the leads and high insulation strength of the material between them.

The circular coil shell type of transformer is built so that the windings are about 80% encased in steel, which protects them from mechanical injury and provides simple and substantial bracing against short-circuited stresses without impeding oil circulation.

The core and coil assembly is bolted together by means of four vertical members of structural steel and cross members formed out of boiler plate. Heavy steel plates notched out at both ends are provided at the top and bottom of the core and arranged to engage with vertical rails welded to the inside of the tank. These are used to center the transformer properly in the tank and provide the bracing necessary to withstand the vibrations incident to shipment. Heavy bolts through the end frames and over and under the core are used to clamp the laminations together. There are no bolts passing through the laminations, which eliminates a possible source of trouble. Long through bolts through the vertical members of the end frame on the same side of the core are used to clamp the coil structure together and hold it securely against the forces incident to heavy loads and short-circuit conditions.

Fig. 18 indicates in detail the relation of the various elements of the construction to each other. Circular coil shell type transformers have proved themselves in service all over the world to be thoroughly adequate to withstand the conditions for which they are designed.

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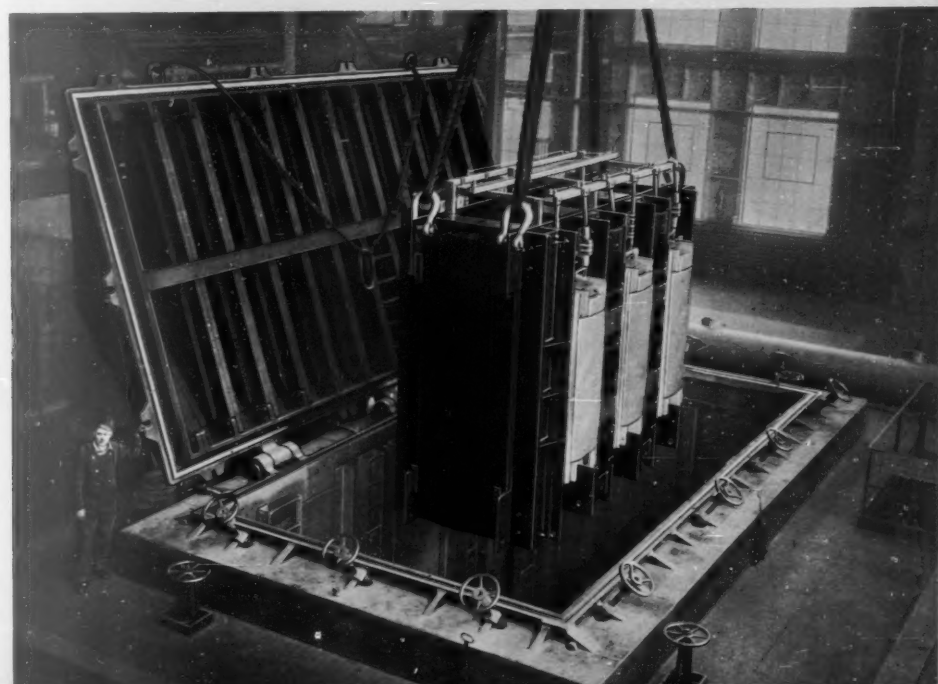
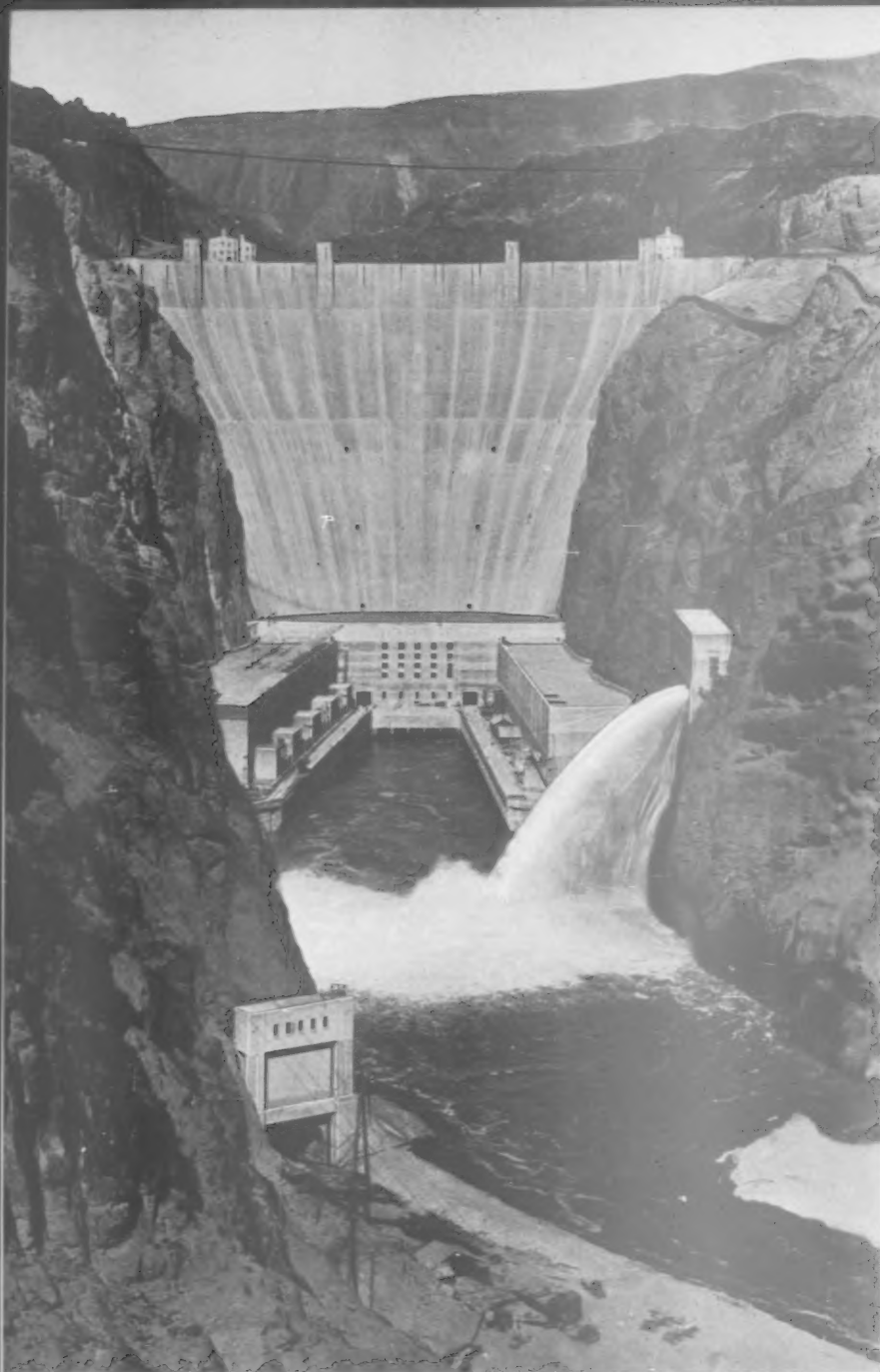


Fig. 20—Vacuum Tank for Drying Transformer Coils



BOULDER DAM

THE WHY OF BOULDER DAM

DR. WM. MONROE WHITE
Manager & Chief Engineer
Hydraulic Department
Allis-Chalmers Mfg. Co.

The Inside Story of the Dam That Today Stands as a Monument of the Fight to Harness Nature

BOULDER DAM stands as a monument to the determination of the people of our Southwestern States to employ the forces of nature to their own advantage by stopping the ravaging floods of a river, by the storage of ample water for irrigation and water supply and by the development of cheap power.

The necessity for the construction of Boulder Dam is the result of the glorious sunshine of Southern California. The delightful climate in the Los Angeles basin is so attractive that the population within that area of 50 miles by 75 miles has increased ten times in thirty years. Sunshine means lack of clouds, and lack of clouds means lack of rain, and lack of rain necessitates irrigation if sufficient food is to be provided for the fast growing population.

The rainfall of the Imperial Valley in California, bordering on old Mexico, is less than 3 inches per year; in Death's Valley, negligent; in California, about 14 inches per year. The average crop requires from 20 to 30 inches of water per year. Irrigation from the Colorado for lands in the Imperial Valley has produced a goodly portion of the food required, but this irrigation has been hampered by the vagaries of the Colorado River from which the supply is taken.

The Colorado River has a length of 1700 miles from the Gulf of California to the upper reaches of its principal tributary, the Green River, which drains the southwestern slope of the Wind River Mountains in Wyoming. The Colorado River drains in part seven states: Wyoming, Idaho, Colorado, New Mexico, Arizona, Nevada and California.

The melting snows from the western slope of the Rocky Mountains causes flood waters which carry into and down the stream an amazing amount of sand, silt and debris. It is estimated that 137,000 acre feet of sand and silt pass down the Colorado River every year, which is an amount of material greater than was removed in the construction of the Panama Canal. The silt laden waters fill up the irrigation canals and the farmers are required to spend huge sums each year to clean the ditches.

After the snows are melted, the river nearly dries up and thus when the farmer most needs irrigation, there is little water to be had. The farmers have urged for years the construction of a dam to stop the ravages of the river and store water for irrigation.

Two hundred million gallons of water per day are now being taken from deep wells in the Los Angeles basin to supply the deficiency of water in that area, and the water table below the ground is being steadily lowered, this notwithstanding the steady supply of about 400 cubic feet of water per second from the Owens River by means of the Los Angeles Aqueduct. There is only one answer to this water shortage and that is that water must be brought in and the only available source is the Colorado River 240 miles away, and so California, through its representatives, has

beseached Congress for years for the construction of a dam.

The Boulder Dam Act was passed by Congress in 1928 and provided for the construction of a dam to accomplish in the order of their importance, the following:

1. The Regulation of the Colorado River
2. Irrigation
3. Water Supply
4. Power Development

The regulation of the Colorado was necessary to stop and eliminate the dangers in over-topping 74 miles of levees now along the north bank of the Colorado River in old Mexico and built to prevent floods from the Colorado washing away the farms in the Imperial Valley in Southern California.

The Colorado River at flood tide discharges about 200,000 cubic feet of water per second, but in the dry season it has been known to be as low as 66 cubic feet per second at Yuma, Ariz. The construction of Boulder Dam provides for a continuous flow of 15,000 cubic feet of water per second through a canal to be built 80 miles long and wholly in the United States, and located just north of the California-old Mexico border and hence its appropriate name, The All-American Canal. An additional canal, 130 miles long, will carry water to the Coachella Valley. The construction of these canals and the supply of water will provide for the irrigation in California alone of about 1,200,000 acres.

The Metropolitan Water District of Southern California was formed by agreement of 13 cities within the Los Angeles basin that bonded themselves to provide together about three hundred million dollars for the construction of an aqueduct to carry 1500 cubic feet of water per second from Parker Dam reservoir on the Colorado River 150 miles south of Boulder Dam, and deliver it to the great Cajalco Reservoir just east of Santa Ana and located within the Los Angeles basin. The aqueduct is being built with a cross sectional area equivalent to 16 feet in diameter. The Aqueduct will pass through 90 miles of tunnels driven through the mountains; 80 miles of these tunnels have already been driven and lined with concrete.

The construction of the aqueduct is as large a problem as the construction of Boulder Dam. The water will be pumped from the reservoir back of the Parker Dam by five pumping stations located along the first 100 miles of the aqueduct and the water will be raised to an elevation of 1350 feet above the level of the water in Parker Dam and will then flow by gravity the remaining 140 miles to Cajalco Reservoir. The construction of the aqueduct would not be justified without ample provisions for a never failing water supply.

Boulder Dam is located in the Black Canyon about 25 miles downstream from the Boulder Canyon and in a narrow box canyon about three-quarters of a mile



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Fig. 1—General View of One of the Four 115,000 hp Turbines for the Boulder Dam Plant, Assembled at the Allis-Chalmers' Erecting Shops

long, about 350 feet wide at water level, and a thousand feet wide at the top of the dam. The dam is 720 feet high from its foundation, 130 feet below the low water level of the river and thus provides a head of 590 feet above low water river level.

The storage reservoir above the dam has a capacity of 30,500,000 acre feet of water. It is by far the largest artificial lake in the world. The water is backed up the Colorado River for 115 miles.

The dam is a concrete gravity arch dam. It extends 650 feet up and downstream at its base. It contains 3,400,000 cubic yards of concrete. It was built under the direction of the Bureau of Reclamation and contains many novel features, one of which was the cooling of the concrete by refrigeration immediately after it was poured.

The work on the dam was started in 1930 and the by-pass gates were shut and storing of water began in February, 1934. Today, August, 1936, the water stands at about 380 feet above low river level. The dam is now in practical use and today about 10,000 cubic feet of water is being discharged through the dam for irrigation and supply in the lower reaches of the river. The average yearly water discharged by the river is half the capacity of the reservoir and since the water is to be passed through the dam to supply the needs below the dam, it is readily understood that now, two years after the gates were closed, the reservoir is less

than half filled. It is expected that it will be two or three years more before the level of the reservoir back of the dam will have reached its ultimate height.

The reservoir has now been named Lake Mead in honor of the late Elwood Mead, Commissioner of the Bureau of Reclamation, under whose direction this great structure was built.

The powerhouse, built in the form of a wide U, extends below the dam, one half in Arizona, one half in Nevada.

It is designed to contain 15 hydro-electric units each rated at 115,000 hp and two units each rated at 55,000 hp, thus providing at Boulder Dam an hydro-electric development of 1,835,000 hp.

The Boulder Dam act provided that the Government would advance the money for the construction of the dam on the condition that contracts would be secured for the sale of the power generated and on such basis that within 50 years the cost of the dam and interest at 5% would be returned to the Government. The Metropolitan Water District has contracted to take 36% of the power; the City of Los Angeles, 13%; Southern California Edison Company, 9%; smaller municipalities, 6%; State of Arizona, 18%; and the State of Nevada, 18%.

The Government does not make a charge for water for use for irrigation and general water supply but the Metropolitan Water District is to pay 25 cents per acre

foot for water used, which means a yearly payment of about a quarter of a million dollars. The Government makes a charge for all water used in the development of power. For firm power a charge is made of 1.63 mills per kilowatt hour for falling water in terms of energy measured at transmission voltage. For secondary power the Government makes a charge of one-half mill per kilowatt-hour for falling water in terms of energy measured at transmission voltage. It is estimated that the annual income to the Government from the sale of water for power will be about \$7,000,000.

The hydraulic turbines at Boulder Dam are the largest by far in the world. They are designed to deliver 115,000 hp at a head of approximately 480 feet. Were the gates of the turbines open wide under the maximum head of 590 feet, each would develop over 150,000 hp.

The turbines are of the Francis type, cast steel, spiral casing, vertical shaft, single discharge, cast steel runner. Fig. 1 (shop view of several hydraulic turbines) gives a view of these turbines when nearing completion in the factory. Each spiral casing is composed of six cast steel sections having a total weight of 450,000 pounds; one of these sections weighs 100,000 pounds. Each spiral casing was assembled in the shop and proven tight under a hydro-static test pressure of 500 pounds per square inch.

The turbine shaft is of forged alloy steel, 38" in diameter with forged flanges on the ends of the shafts 63" in diameter. The cast steel runner weighs 70,000 pounds.

The first of the four 115,000 hp hydraulic turbines is for driving the generators to supply current to the City of Los Angeles. This current will be transmitted from Boulder Dam to the step-down station in Los Angeles over a distance of 270 miles, at a voltage of about 285,000.

When the Boulder Dam and powerhouse, the Metropolitan Water District Aqueduct, the Parker Dam and powerhouse, the All-American Canal, the Coachella Canal, the distribution irrigation canals, and the distribution network around the City of Los Angeles have all been completed and put into operation, the peoples of the southwestern part of our country will have stopped the ravages of a heretofore uncontrolled river, will have stored water and provided means to distribute it upon acres of rich land for the growth of abundant crops, will have secured ample water to supply a population of twice that now existing throughout this great empire, will have made available cheap power for light, for distribution, for manufacturing, for chemical uses and thus have provided all the essentials requisite for a happy, industrious, and ultimately a tremendous population.

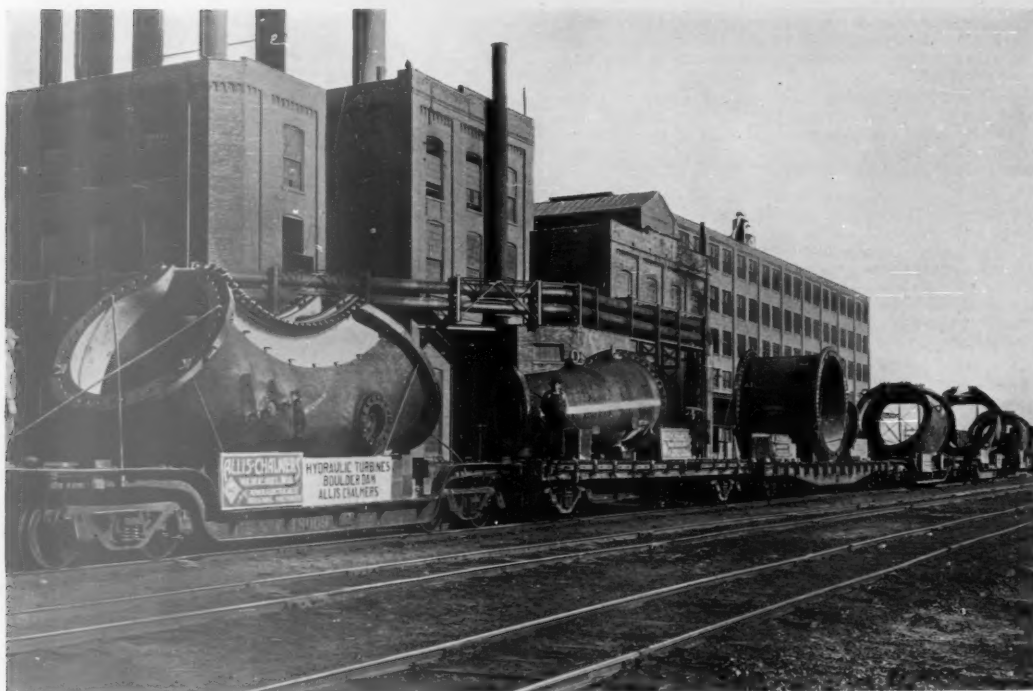


Fig. 2—These Six Carloads Ready to Leave the Allis-Chalmers Freight Yard Comprise the Six Cast Steel Casing Sections of the First of Four 115,000 hp Turbines for the Boulder Dam Power Plant. Total Weight 450,000 lbs

The Quick Clean Motor for Cotton Mills

W. D. SHANNON

Norwood Works
Allis-Chalmers Mfg. Co.

IN THE first applications of electric motor drive to spinning frames and other similar machinery in cotton mills, the effects of dust laden atmosphere was not taken into account or fully realized by motor manufacturers. The result was that standard open type motors of conventional design were applied to this class of machinery in the textile industry. The dust present in the spinning rooms, consisting of small particles of lint, had a tendency to collect inside the motor and thus prevent proper cooling. Frequent cleaning of the motors was required to keep the temperatures within safe operating limits.

The cleaning process consisted of compressed air applied to the motor by means of a special nozzle. This procedure was only partially effective for the reason that the lint adhered to the inside of the motor at certain points and a perfect cleaning could only be accomplished by dismantling the motor. This made the expense of maintenance unusually high. Not infrequently motors would burn out because of the excessive temperatures through lack of ventilation, and this resulted, also, in loss of production. From time to time various changes in the mechanical design of motors were undertaken in order to combat this condition, such as placing screens on the air intake and enlarging the air passages so as to cause more freedom in the ventilating air flow.

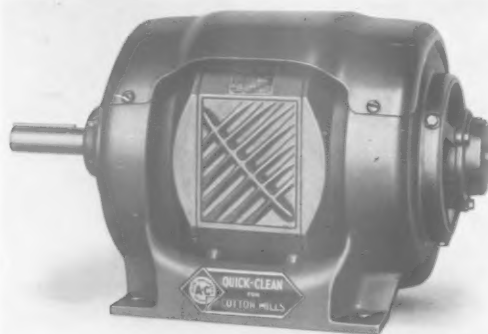
When the totally enclosed fan cooled motor was developed it was applied in some installations, but the desired results were not obtained with this type of motor. Frequent cleaning was necessary to keep the circumferential air channel free of lint.

This led to the development of the open type textile motor with the least possible obstruction in the cooling air path and the walls of the air passages finished to a smooth surface. Incorporated in this design was the Seal-Clad construction, which completely encloses the windings at both ends of the stator. This was found to be a considerable improvement over the standard commercial type motor, but did not prevent the collection of lint sufficiently to eliminate frequent cleaning.

The textile industry was waiting for the development of a motor that would require only nominal maintenance and permit normal production without interruption. This demand was met in the development of the QUICK-CLEAN motor.

In mechanical design, the QUICK-CLEAN motor is a radical departure from any construction heretofore employed. Special features provide complete protection from cotton accumulation in the motor. The stator windings are completely enclosed. Hard, smooth bakelite shields sealed over the stator coils, provide permanent protection against lint or dust or penetration of other agents injurious to motor insulation. The stator is supported rigidly on the motor base. The bearing supports are an integral part of the base. A removable plate at the top serves to protect the stator. Cartridge mounted ball bearings are used, grease lubricated and sealed.

As will be seen from the accompanying illustrations, the ventilating air path is wide open and unobstructed, the stator at both sides being completely exposed.



Assembled Motor

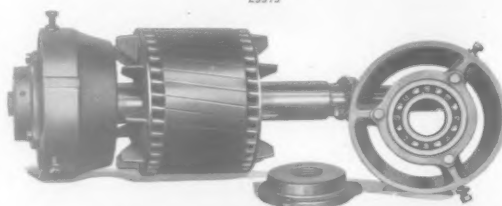
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The QUICK-CLEAN motor is applicable to individual spinning and twisting frames and is available in the following ratings—

5—7½ and 10 hp, 1200 rpm

7½—10 and 15 hp, 1800 rpm

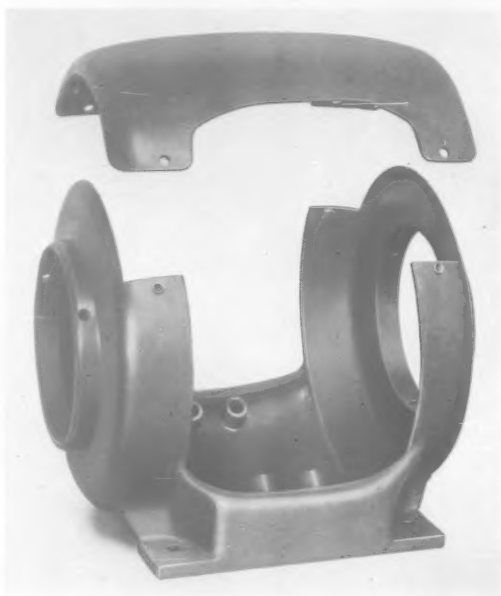
Satisfactory performance in service is evidenced by the ready acceptance by many cotton mills and the favorable comments of the operators.



Rotor With One Bearing Removed

22973

31300



Base and Bearing Support and Top Cover

REACTIVE CURRENT

S. H. MORTENSEN
Engineer-in-Charge A.C. Design
Allis-Chalmers Mfg. Co.

and
PROFESSOR G. F. TRACY
University of Wisconsin

LAGGING reactive current, frequently termed "wattless" current, is one of the phenomena encountered in alternating-current circuits which does not arise in direct current circuits where Ohm's Law in its simplest form holds good under steady state operation. An understanding of reactive current, of the factors which govern its magnitude, its influence on operation, and how it can be controlled, are subjects, therefore, with which the designer and user of alternating-current equipment should be concerned. Much has been written in the technical press on this subject, and at present the discussion is actively centered on the real meaning of reactive power and the proper method of charging for it. The present paper is confined to a discussion of the more fundamental aspects of the subject of reactive current and power factor correction.

It is fundamental that a conductor which carries a current is surrounded by a magnetic field, the magnitude of which is proportional to the strength of the current. This magnetic field is greatly enhanced if the conductor is wound into the form of a coil and particularly if the coil is so mounted that the path of the magnetic flux is primarily within iron as in an electrical machine. The well-known relations between current and voltage when an alternating current is passed through such a coil is shown in Fig. 1. The effect of the magnetic flux is to make the current lag behind the voltage by an angle ϕ . The current may be considered as composed of two components: the energy component I_w and the reactive, or wattless, or magnetizing component I_m . This latter component may be considered responsible for setting up the flux. It cannot be put to any mechanical use, but is indispensable in that it establishes the magnetic field required for the creation of emf in generators and torque in motors. The reactive component of current represents energy which is drawn from the source and stored in the magnetic field during the first quarter of each cycle, returned to the source during the second quarter, stored again in the field during the third quarter, returned again during the fourth quarter, etc. No net energy, however, corresponds to the reactive component of current.

Fig. 2 is a schematic picture of an induction motor where the fields due to the lagging reactive or magnetizing current are depicted. An expression for the factors which determine the magnetizing kva required for a main motor field is

$$kva = \frac{B^2 f V}{4}$$

where B is the average air-gap density,
 f is the frequency,
 V is the flux volume in air.

This expression shows that the higher the gap density (which is governed by the motor pull-out torque), the higher the magnetizing kva. The magnetizing kva

Effects of Magnetizing Current in A.C. Machinery and the Economies Gained by High Power Factor

is also directly proportional to frequency. Since the flux volume is equal to the rotor surface times the gap length, the larger the rotor the more magnetizing kva. As rotor size is inversely proportional to speed for a given horsepower rating, the above expression shows

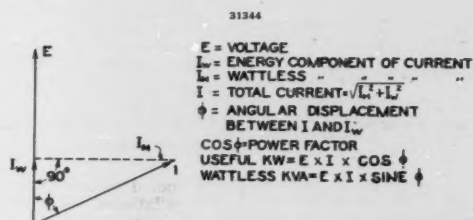


Fig. 1—Components of Current in an A-C Circuit

why slow-speed motors and oversize motors require large magnetizing kva. It also shows why a short air-gap, generally $\frac{1}{4}$ of one per cent of the pole pitch, is required to keep the motor magnetizing current within the range of 20% to 80% of rated current.

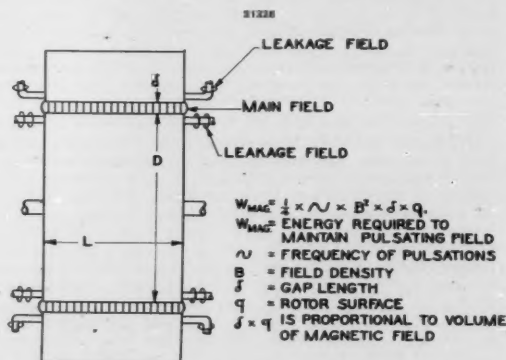


Fig. 2—Magnetic Field of a Polyphase Induction Motor

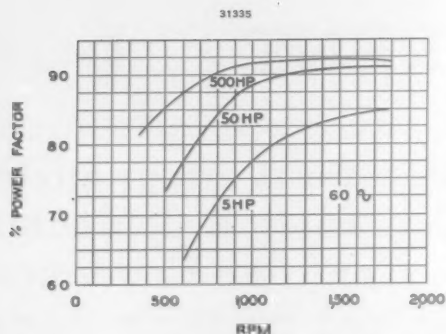


Fig. 3a—Representative Full Load Power Factors of 60 cycle, Squirrel Cage Induction Motors

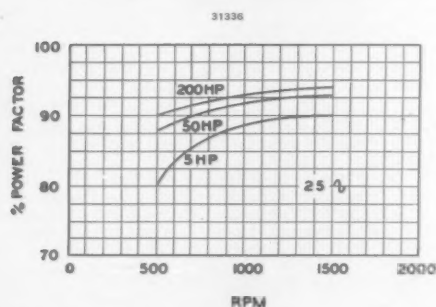


Fig. 3b—Representative Full Load Power Factors of 25 cycle Squirrel Cage Induction Motors

In Figs. 3(a) and 3(b) are shown average power factors that may be expected on modern squirrel cage induction motors plotted with respect to rated motor speed. It is readily seen that the lower speed motors have decidedly lower power factors, which means more reactive current. Fig. 4 shows how the power factor drops off as the load is decreased. The energy component of the current decreases as the mechanical load decreases but the magnetizing component stays approximately constant thus lowering the power factor.

All inductive apparatus such as transformers, self-excited motors, arc furnaces, reactance coils, etc., require magnetizing current. In the case of distribution transformers it is particularly important to keep the magnetizing current as low as possible since there are large numbers of such transformers on a system and they are connected 24 hours a day. They must be designed so that the magnetizing current lies between 1% and 15% of full-load current depending on the type of service in which the transformer is to be used.

What are the objections to low power factor? In the first place since the copper loss in transmission, distribution and generation equipment is proportional to the square of the total current; and since the total current is greater for a given horse-power output at low power factors than at unity power factor, it follows that the copper loss is larger than it would be at unity power factor. It is larger by approximately the square of the reactive component of the current. At a power factor of 70.7%, for example, the active and reactive components of current are equal; and the copper loss is double what it would be for the same electrical power at unity power factor. This necessitates, for a given output, more copper in the transmission and distribution system than at unity power factor; and

also larger capacity generating and transforming equipment than would be required at unity power factor. Fig. 5 shows how power factor affects the rating of a 121,000 kva, turbo-generator with constant field excitation. It will carry 146,000 kva at unity power factor but only 103,000 kva at 80% power factor.

In the second place power factor affects the voltage regulation of transmission lines and distribution equipment such as transformers. Fig. 6 shows the voltages at the sending end and the receiving end of a transmission line for the two cases of lagging and leading

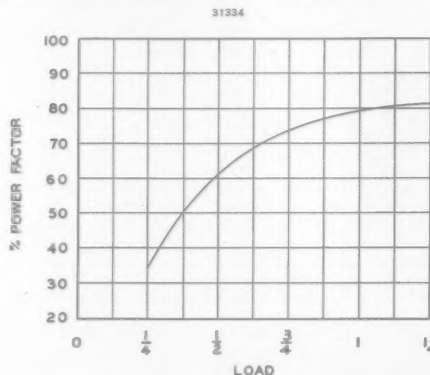


Fig. 4—Variation of Power Factor With Load on a 250 hp, 300 rpm, 60 cycle Induction Motor

current. It is seen that the line reactance drop, which is always 90 degrees ahead of the current, has the effect of making the receiving end voltage lower than the sending end voltage in the case of the lagging power factor, whereas the reverse is true in the case of the leading power factor. A similar argument applies to a transformer. As an example take a 15,000 to 2300 volt transformer with 1 1/2% resistance drop and 8% reactance drop. Based on rated kva at unity power factor its voltage drop would be 1 1/2% but at rated kva, and 70% power factor, it would be 7% or 5.6 times that for unity power factor.

From the foregoing, it is apparent that, necessary as the reactive current is, its effects are undesirable and its control becomes important. Generally speak-

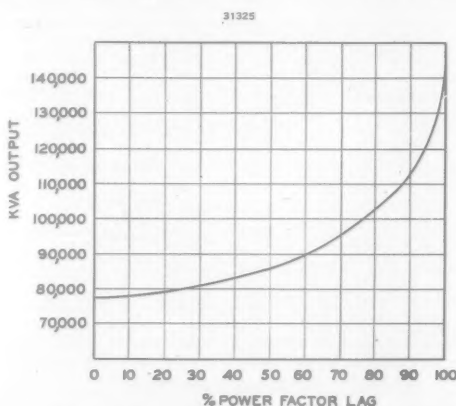
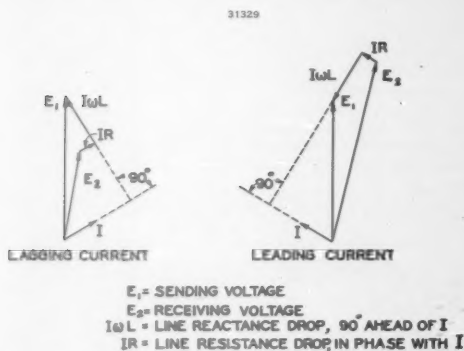


Fig. 5—Effect of Power Factor on Output of a 121,000 kva Turbo-Generator

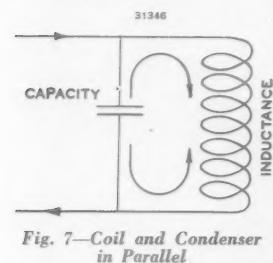
ing, there are two procedures open when attempting to correct for low power factor. The first is a judicious choice of equipment with respect to its magnetizing current requirements, so that the magnitude of the reactive current is kept as low as possible. The second is to add to the system corrective equipment which draws a leading reactive current and thus compensates for all or part of the lagging reactive current. In Fig. 7 is shown a simple case of a condenser in parallel with a coil, in which case the leading current taken by the condenser compensates for the lagging current taken by the coil and so reduces the magnitude of the current



drawn from the system. In this case there is a periodic exchange of magnetizing energy between the coil and the condenser.

The main field of an induction motor may be set up by magnetizing current circulated in either its stator or its rotor winding. While the power factor of an induction motor, connected in the usual way with its rotor short-circuited and its stator carrying the magnetizing current, is low; it may be made unity if its rotor is supplied from a separate source with excitation of the proper magnitude, frequency and phase. Further, by over-exciting the rotor, the stator will draw a leading current from the line, which will help to compensate for the lagging reactive current drawn by other equipment. The magnetizing kva necessary to excite the machine will be much smaller when supplied through the rotor than through the stator, since the rotor frequency is that of its slip; and the formula previously given shows the magnetizing kva to be proportional to slip.

One practical arrangement in which an induction motor is supplied with excitation through its rotor is the phase advancer as shown in Fig. 8. This has not become generally popular in the United States as it is not applicable to squirrel-cage motors or to installations where the motor must be started frequently or its speed varied. The amount of correction is also fixed. It has the further obvious disadvantage of requiring the extra machine which adds materially to the cost.

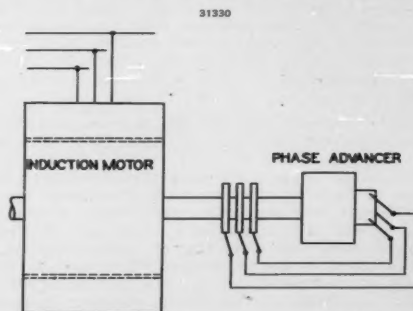


It is of interest to observe that when an induction motor, having its excitation supplied through the rotor, runs at synchronous speed, the frequency of the rotor exciting current is necessarily zero. The machine then becomes a synchronous motor with d-c excitation. Its magnetizing kva is consequently small, since the ampere-turns required for a given field are independent of the frequency; while the voltage required to circulate the exciting current is proportional to the impedance. At zero frequency the impedance, of course, reduces to simply the ohmic resistance. This permits over-excitation at low magnetizing cost. Advantage is taken of these features in the synchronous-induction motor ("Hytork" motor), which in a general way is a wound-rotor induction motor provided with d-c excitation through its rotor. It starts as a wound-rotor motor, and is pulled into synchronism by means of its d-c excitation after reaching its maximum induction-motor running speed. In comparison with a synchronous motor its magnetization is somewhat less effective because of the distributed field ampere turns; and it, therefore, requires not only larger field excitation but its capacity for over-excitation is quite limited. Consequently it cannot compete with the synchronous motor except in installations imposing high starting torque and low starting kva.

A special form of synchronous-induction motor known as the "Fynn-Weichsel" motor derives its own excitation in a manner similar to a synchronous converter; i.e., by means of a commutator and additional brushes. This motor operates at leading power factors over its working range. Its higher cost and additional complication, however, has mitigated against its general adoption in spite of its desirable power factor characteristics.

The synchronous motor is the principal means used today for obtaining power factor correction. From this point of view, synchronous motors may be divided into three classes: those that operate normally at unity power factor, those that operate normally at a leading power factor, and finally those that do no mechanical work but are used entirely for power-factor correction or voltage regulation.

A 100% power-factor synchronous motor does not compensate for reactive current when fully loaded. On partial loads its power factor will become leading provided its excitation corresponds to its rated load. Fig. 9 shows power factor against per-cent load for a 100% power-factor synchronous motor with its excitation maintained constant at its normal value. As the power factor of a system is a function of the relative values of active and reactive components of current, the addition of a 100% power-factor motor means some improvement in system power factor. This may, under certain circumstances, be sufficient to accomplish the desired results. If not, synchronous motors with ad-



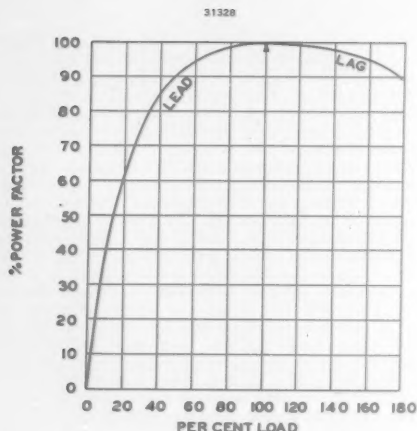


Fig. 9—Power Factor of a 100% pf Synchronous Motor with Excitation Held Constant at Normal Value

ditional capacity for power-factor correction should be used. Although this means a larger and somewhat more expensive motor, a considerable amount of leading reactive kva is available. An 80% power-factor motor (one designed with sufficient field capacity to deliver rated horse-power output at 80% leading power factor) may cost 14% more and have 1.5% lower efficiency than a 100% power factor motor, but it will give 60% corrective kva at full load. With slow speed motors conditions are less favorable as to first cost and efficiency, and careful consideration should be given to all factors involved before deciding whether to install 100% power-factor motors and obtain power-factor correction by other means, or machines with additional capacity for power-factor correction. Also, a great many installations are not suitable for synchronous motor drive; particularly those requiring small horse-power driving motors where the lower cost and rugged simplicity of the squirrel cage induction motor makes it superior in spite of the fact that it is the largest single consumer of reactive current.

A synchronous motor that does no mechanical work but is operated for correcting power factor only is referred to as a "synchronous condenser." This type of machine is indispensable in voltage control, its excitation being adjusted within its capacity so that it takes leading or lagging current in a quantity insuring constant voltage at its terminals. The kilowatt loss in this type of machine must be charged against itself and not against a load as would be the case in a partly mechanically and partly electrically loaded synchronous motor. For this reason, the synchronous condenser is designed with as low losses as possible; and, to keep its cost down, it is designed to operate at the most economical speed. This leads in general to high speed design.

Static condensers are on the market, suitable for direct connection to feeder systems with voltages as low as 220 volts. For 2300 volts, units of 5 kva capacity are available. These units have the advantages of requiring no foundation, attendance or upkeep; have no moving parts, and can be installed either singly or in groups at the motor terminals or at any part of the feeder system. The efficiency of these condensers is within a fraction of a per cent of 100%, and for capacities up to at least 500 kva their cost is lower than rotating condensers with their starting equipment. Hence this type of equipment is becoming increasingly popular for installation at scattered points in a system

where power factor improvement rather than voltage regulation is the principal consideration.

A great deal can be accomplished by guarding against over-motoring. One large driving motor is preferable to a large number of small individual drives, as far as reactive current demand is concerned. The same pertains to transformers. The evil influence on motors of sub-normal voltage is generally appreciated, but over-voltage on induction motors and transformers should also be guarded against. It may be perfectly safe to operate a motor on 10% over-voltage as far as its heating is concerned, but its magnetizing current may easily be increased by 20%. In the case of a transformer a 10% over-voltage may increase its magnetizing current 50% or even 100% over that required at normal voltage. So checking the impressed voltage against the name-plate voltage may lead to a decided saving in reactive current and power cost, and improve the voltage regulation. As an example, in one industrial installation, the station power factor was raised from 72% to 76% by the simple expedient of reducing the generator voltage to a value giving the rated motor voltage at the various motor terminals.

In order to determine the resultant power factor and resultant kva of two or more loads the method shown in Fig. 10 may serve as a guide. The diagrams are self explanatory. Lagging reactive kva has been represented by a vector drawn vertically downward in order to conform with the corresponding reactive component of current.

After the causes of low power factor have been located and eliminated as far as practicable by the means suggested above, consideration must be given to the intangible and tangible benefits that may accrue from power factor improvement. The tangible benefits include factors affected by voltage regulation whose improvement means better speed regulation of motors, better light; and with these, larger production, more uniform product, etc. The tangible assets are those

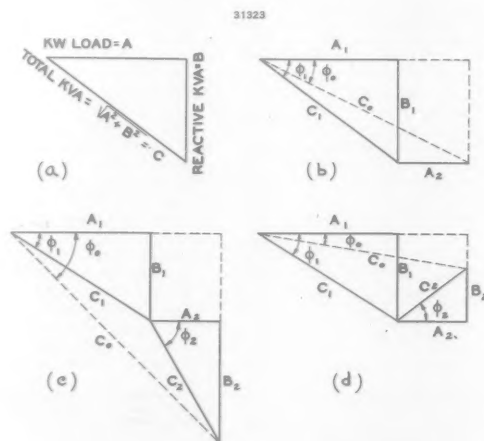


Fig. 10—Resultant kva and Power Factor of Two Loads

- (a) Relation between kw, reactive kva, and total kva.
- (b) Lagging power-factor load combined with 100% power-factor load.
- (c) Two lagging power-factor loads combined.
- (d) A lagging power-factor load combined with a leading power-factor load.

$\cos \phi_1$ = power factor of load 1,
 $\cos \phi_2$ = power factor of load 2,
 $\cos \phi_0$ = power factor of combined load.

whose value can be predetermined and are in the nature of reduced losses and increased efficiencies. The extent, however, to which equipment for correcting power factor should be installed is an economic problem in which the reduced cost of power generation and distribution combined with the benefits resulting from improved voltage regulation on the distributing system must be balanced against the cost of the corrective equipment, its installation and operation. The least power loss in transmission lines, networks, feeders, motors and other equipment would result with unity power factor operation. But the required corrective equipment may become entirely too costly, since the percentile cost for each per cent of power factor correction increases as unity is approached. It will be found in many installations where the network, cables, etc., are adequate for 80% power factor leads, that this power factor is the most economical, since generators are usually rated for 80% power-factor.

A preparatory study of power factor improvement and to what extent it is economical must take into consideration therefore not only the cost of corrective equipment but also power rates and energy saving. For bought power a number of widely varying power billing methods are in force on different systems. Most of them, in some manner, include a correction of the billing rates by bonuses or penalties; the extent of the correction depending upon the amount by which the operating power factor is higher or lower than a basic assumed power factor. Considerable improvement in power factor has been achieved on certain systems where the power rate includes a flat allowance proportional to the customers' connected synchronous kva

TABLE I
Industrial Load I

	Kw	Power-Factor	Reactive kva
Light	100	1.00	0.
Synchronous Motors	200	.80 Lead.	+150. Lead.
Induction Motors	500	.70 Lag.	-510. Lag.
Ind. Motor-Gen. Set	400	.85 Lag.	-250. Lag.
Total	1200.	.892	-610. Lag.

Industrial Load II

	Kw	Power-Factor	Reactive kva
Light	100.	1.00	0.
Synchronous Motors	200.	.80 Lead.	+150. Lead.
Induction Motors	500.	.70 Lag.	-510. Lag.
Synchr. Motor-Gen. Set	400.	1.00	0.
Total	1200.	.958	-360. Lag.

Industrial Load III

	Kw	Power-Factor	Reactive kva
Light	100.	1.00	0.
Synchronous Motors	200.	.80 Lead.	+150. Lead.
Induction Motors	500.	.70 Lag.	-510. Lag.
Ind. Motor-Gen. Set	400.	.85 Lag.	-250. Lag.
Static Condenser	0.	0.00 Lead.	+250. Lead.
Total	1200.	.958	-360. Lag.

Industrial Load IV

	Kw	Power-Factor	Reactive kva
Light	100.	1.00	0.
Synchronous Motors	200.	.80 Lead.	+150. Lead.
Induction Motors	500.	.70 Lag.	-510. Lag.
Synchr. Motor-Gen. Set	400.	.90 Lead.	+194. Lead.
Total	1200.	.99	-166 Lag.

capacity (properly adjusted), irrespective of other operating conditions. In making a study of this kind, a tabulation similar to that in Table I may be helpful. This table shows an original industrial installation having a power factor of 89.2% and a basic load of 1200 kw. The benefits obtained by the addition of a static condenser for correcting power factor, and by substituting a synchronous-motor drive instead of an induction-motor drive for the motor-generator set are shown. By duly considering equipment costs, efficiencies, and power rates, the best solution can be worked out and the desirable correction determined.

No study of power factor correction is complete without giving due consideration to the relative location of the compensating equipment and the magnetizing-current-consuming equipment. The rule that the closer the corrective equipment is installed to the low power-factor load the better it is, cannot always be followed. As an example, a utility may find it necessary to place the corrective equipment at strategic interconnection points, in substations, or in very rare cases in the generating station. In the latter case it is usually cheaper to provide generator capacity adequate to take care of reactive requirements rather than to supply the energy component from the generator and the reactive component from condensers. This point is illustrated in Table II. The type of corrective equip-

TABLE II

Power system load = 10,000 kva at 80% power-factor
Energy component = 8,000 kw
Reactive component = 6,000 kva

The cost of an 8000 kw, 6600 volt, 80% pf, 3 phase, 60 cycle, 300 rpm generator would be \$46,500. Its full load efficiency would be 97%.

The cost of an 8000 kw, 6600 volt, 100% pf, 3 phase, 60 cycle, 300 rpm generator would be \$39,400, with a full load efficiency of 97.1%. A 6000 kva, synchronous condenser would cost \$23,300. Its losses would be 136 kw, or 1.7% of the generator kw load.

	80% pf Generator	100% pf Generator and Synch. Condenser
Initial Cost of Generator	\$46,500	\$39,400
Initial Cost of Condenser		23,300
Total Cost	\$46,500	\$62,700
Losses in Generator	3.1%	2.3%
Losses in Condenser		1.7%
Total Losses	3.1%	4.0%

ment that lends itself most readily to correction at the source is the static condenser. Here, a reduction in total current to be supplied by the generator is desired rather than improved voltage regulation.

Let it be reiterated that power factor control is altogether an economic proposition; and, as such, is a phase of the business of power generation and distribution. When spending money intending to save money, it must be kept in mind that the annual cost involves two items; viz., operating cost and fixed cost. An energy loss is an operating expense which exists only as long as the load is being carried. Corrective equipment requires capital investment which adds to the fixed charges. Hence, when considering the financial end only, a saving must be shown which is sufficient not only to carry interest on money invested but also an excess sufficient to pay off the original investment in a reasonable length of time.

Patent Fundamentals for Engineers

H. S. SILVER
Patent Attorney
Allis-Chalmers Mfg. Co.

Some Tips for the Prospective Inventive Engineer

WHEN an engineer has knowledge of a patent which he infringes or desires to avoid infringing he consults his patent attorney and when he is sick or desires to avoid sickness he consults his doctor. Both actions are proper for the fields are specialized and the men trained in these respective fields are usually better equipped than is the engineer to give an opinion on the problem. However, the fact that the engineer consults his doctor on problems of bodily health does not prevent his knowledge of the fundamentals of physiology and the rules of good health and applying common sense reasoning to such knowledge and rules to minimize sickness and to be of great help to the doctor in solving health problems. It is believed that if the engineer has a knowledge of the fundamentals of patents and the general rules in regard thereto and if he will similarly apply common sense reasoning to such knowledge and rules he can minimize patent troubles and be of great assistance to his attorney in solving patent problems.

Fundamentally, a patent is a contract between the government, as the representative of the people, and the inventor. The government, in accordance with constitutional provision, and in order to promote the progress of science and the useful arts, obtains from the inventor a disclosure of the invention which disclosure will be turned over to the public and after a given period of years may be used by anyone. In return for this disclosure the government gives to the inventor the right, for a period of seventeen years, to prevent others from utilizing the invention.

There are three basically important points of the patent contract which should be carefully considered and kept in mind when considering patent situations. (1) The purpose behind the monopoly given by the government is to "promote the progress of science and the useful arts." (2) The monopoly is given in return for the disclosure made. (3) The monopoly right is that of the inventor preventing others from utilizing the invention.

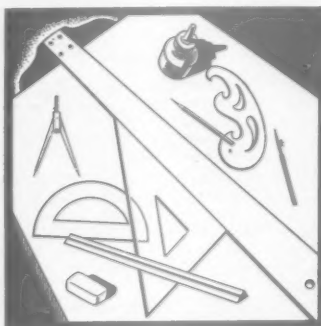
Considering the first point, it is obvious that the progress of science and the useful arts is promoted by substantial discovery or invention which adds to human knowledge or makes a step in advance in the useful arts and not by slight refinements or changes which are within the skill of the ordinary workman. There must be something of real value given, something the

world did not have before, some benefit to mankind, and if none of these is present, no valid patent can be granted.

In view of the fact that the monopoly is granted in return for the disclosure of the invention it follows that the monopoly cannot be granted for something not disclosed. The patent statutes require a written description of the invention "and the manner and process of making, constructing, compounding and using it, in such full, clear, concise and exact terms as to enable any person skilled in the art or science to which it appertains, or with which it is most nearly connected, to make, construct, compound, and use the same." Therefore, if a disclosure is vague and indefinite or so meager and incomplete that it needs further experiment to utilize it, no valid patent monopoly can be granted in return therefor.

The third point that a patent right is a preventive right is one not usually understood by engineers. The fact that you have been granted a patent monopoly gives you no right over any you previously had to utilize the invention. Your utilization of your invention may be treading on ground forbidden by monopolies granted to other inventors and a patent granted to you does not guarantee you against infringement of other monopolies. You are, by your patent, granted the right to use the courts to prevent others from utilizing your invention.

Bearing in mind the above fundamentals, let us look at the mechanics of a patent, that is, the function of the two important parts thereof and their relation to each other. The patent consists essentially of a statement of the invention, including a description of one or more particular embodiments of the broad invention, and usually including a drawing, and one or more claims which define the limits of the monopoly granted. The function of the statement of the invention including the specific description, and usually referred to as the specification, is to tell the story of the invention. It may properly bring in a general picture of the state of that particular art at the time the inventor entered the field. It may set forth the disadvantages of the prior art and therefore the problem confronting the inventor at the time of his invention. It then sets forth the manner in which the inventor has solved the problem usually by description of one or more particular embodiments of his invention. It is a dictionary for



the terms used in defining the monopoly granted. When published, it limits future inventions to those constituting a substantial advance over what is disclosed therein. The statement of invention describes the outer limits of any particular monopoly that can be validly granted by the patent.

The inventor is required by statute to "particularly point out and distinctly claim the part, improvement or combination which he claims as his invention or discovery." This he does in one or more paragraphs at the end of the description, which paragraphs are called claims, and each of which defines the extent of the monopoly granted by such claim. To one not versed in the function of the claims and the reasons therefor, these claims appear to be such a conglomeration of abstractions and legal verbiage as to be not only unintelligible but to be far from telling what the invention is. It must be remembered that the claims are not written for the purpose of describing or explaining the invention. The only function of the claims is to lay an exact boundary of the ground forbidden to others. If the inventor in his patent merely described his invention, the public in general would have to search out the step in advance that such inventor had made and on which the monopoly was granted. The statutes provide against this by requiring the inventor to state exactly that from which the public is to be excluded, a categorical inclusion of the essential invention elements to which one can refer and determine whether or not the construction he desires to use is exactly or equivalently the thing forbidden.

Obviously, the inventor desires his monopoly to cover as much ground as it can. When the inventor makes his invention, his ideas are concrete and he has a specific embodiment in mind and upon analysis he will find a broad generic class which when stated as generalizations, both structurally and functionally, will include his concrete and specific embodiments and all proper equivalents. His specific means for accomplishing his desired result may, for example, include a current transformer connected in a load circuit and functioning to energize a trip coil of a circuit breaker upon overload to cut off the supply of power. Upon analysis he finds that this element of his invention may be responsive to voltage rise or fall, to reverse energy flow to power factor change and various line conditions of surge, ground or short circuit and that the desired functioning may be to cut out the line, to cut in resistance or to slow down or speed up the supply generator. As recited in broad language in the claim, this element therefore becomes a "means responsive to a predetermined circuit condition for controlling the circuit." Obviously, such language does not describe or explain the invention, but it does lay down an exact boundary of forbidden ground.

To summarize, patent monopoly (embraced in a claim or claims) is given to an inventor in exchange for a complete disclosure (embraced in the specification) of a substantial invention or discovery which promotes progress of science and the useful arts, and such monopoly permits him for the life of the patent to prevent others from utilizing the invention.

Specific examples of how this information of fundamentals may be used by engineers is suggested below: When considering patents to see if a given construction infringes

1. Consider each claim separately.
2. Does each essential element thereof or its equivalent appear in the given construction? If not, no infringement.
3. If the construction infringes, does it come within the broad scope of the invention disclosed in the specification and is it within the statement of the invention? If not, the claim would not be held valid by a court.
4. If the claimed construction is within the disclosure, is it a substantial advance over prior constructions? Is it invention over a construction described in the specifications of patents of prior inventors? (Remember that although some patents may be dated earlier, the inventors may not be prior.) If not, the claim would not be held valid.
5. If the construction comes under 2, 3 and 4, then in considering how infringement may be avoided, determine what essential element of the claimed construction can be omitted and the desired result obtained.

When considering an invention as material for a patent application

1. Has a complete and clear written disclosure of the invention been made, signed and dated?
2. Has such disclosure been made to and understood by others, witnessed and dated?
3. Is it a substantial advance over prior construction including that disclosed in patent specifications of earlier inventors?
4. Has such disclosure been analyzed to determine broad generic language that will include all other embodiments of the invention?
5. Has the inventor made a statement of his invention in the broadest terms which will still avoid prior constructions of which he has knowledge?

The above consideration is concerned merely with the fundamentals and after such consideration, if you desire to know whether or not a given construction infringes a patent or whether it is patentable—Consult your Patent Attorney.



U. S. Patent Office, Washington, D. C.

New Rheostatic Generator Voltage Regulator

Designed for Control of Large Synchronous Machines Where Accurate Voltage Control, High Speed Voltage Recovery, and Reliability Are Essential

F. C. LUDINGTON
Switchgear Division
Allis-Chalmers Mfg. Co.

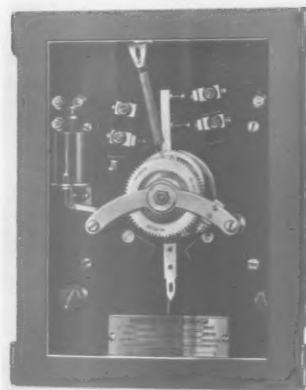


Fig. 1—Voltage Control Element

THE new type "J" Rocking Contact Rheostatic Voltage Regulators have been designed for the control of large and important synchronous machines where accurate voltage control, high speed of voltage recovery and reliability are essential.

The design incorporates high speed features as well as maintains the successful time proven rocking contact design of the smaller regulators. The motor operated rheostat is a major item in the complete regulating equipment. This rheostat is constructed on the rocking contact principle, but on a larger scale than employed in standard regulators and provides a greater number of steps that are of higher current carrying capacity. When machine voltage is normal, the entire regulating equipment is at a standstill, thus assuring a minimum amount of wear resulting in practically no maintenance or renewal part expense.

The three main parts of the complete regulating equipment consists of the voltage control element, Fig. 1, and the rocking contact rheostat and high speed contactors, Fig. 2. The voltage control element is connected to the machine to be regulated and operates its contacts when the voltage differs from the normal value for which the control element is set. The rocking contact rheostat is the means for varying the field current and adjusting it to the correct value to give normal generator voltage. It operates from contacts on the voltage control element. A set of high speed contactors temporarily adjust the field current to hold the voltage near normal if the rheostat must make a large change requiring a certain time to travel from the old to the new position. These contactors also operate from contacts on the voltage control element.

Operation of the Voltage Control Element

A three phase torque motor energized from the generator voltage has its torque opposed by a spring. When the torque, due to voltage, just balances that due to the spring, the rotor of the control element remains stationary. If the voltage falls, the rotor moves in one direction and two undervoltage contacts close separate circuits. If the voltage rises, the motor turns in the opposite direction and two overvoltage contacts close two other separate circuits. Each of the two sets of contacts are separately adjustable so that one can be set to make at a small deviation from normal and the other set to make on a larger deviation. Control circuits thus operate the rheostat on small and large voltage changes, and the high speed contactors only on large voltage changes.

Operation of the Rocking Contact Rheostat

The resistance of the rheostat is varied by sectors rocking over and changing point of contact on a stationary commutator to which the resistor steps are connected. The sectors are connected to short out the resistors as they move from one end of the commutator to the other. Rocking of the sectors is performed by a reversing motor through a gear reduction. The motor is controlled by the control element contacts through suitable auxiliary relays. The resistance of the exciter field circuit is thus adjusted automatically to maintain normal generator voltage.

Operation of the High Speed Contactors

The two contactors each control forcing resistors in the field circuit. The voltage raising contactor can close its normally open contact to short out all rheostat and other resistance thereby applying maximum field strength. It does this when the control element contact for large undervoltage closes its circuit. The voltage lowering contactor can open its normally closed contact to insert a block of resistance into the field circuit thus reducing field strength. This is done when the control element contact for large overvoltage makes its circuit. The powerful effect of either of these contactors will return any voltage change to normal or somewhat beyond. As soon as normal voltage is reached, however, the control element contact opens and the contactor returns to normal position. Corrective forces being removed, the voltage deviates from normal again. This causes repeated operation of the control element and the contactor and this vibration set up will maintain an average field current which holds the machine voltage at approximately normal level.

Operation of the Complete Regulator

With normal voltage the control element contacts (both undervoltage and overvoltage) remain open. Assume the voltage varies beyond a normal value of plus or minus $\frac{1}{2}$ of 1% due to a change in generator load. If the change is small, only the motor operated rocking contact rheostat is moved. The control element will begin to vibrate and the rheostat will start to inch along to correct voltage. When the voltage comes within the normal band (the percentage range of voltage within which neither the undervoltage nor overvoltage contacts will close) the rheostat movement stops. Thus the voltage is returned to normal without hunting or excessive overshooting.

The above operation is stable because the corrective action of the regulator has a fast rate as long as the terminal voltage differs from normal by a definite amount. However, as soon as the voltage closely approaches normal after the deviation, the corrective action is slowed down proportionately, thus preventing overshooting. The sequence accomplishing this is as follows: The control element opens its contact and starts to vibrate before normal voltage is reached because its adjustment has been lowered a small percentage at the time the auxiliary relay started the rheostat motor. In effect, the control element opens because it is temporarily set to regulate for a new voltage of a lower value. The adjustment is done by contacts of the auxiliary relay short-circuiting some of the resistance in series with the torque motor of the control element. This relay is then de-energized with the opening of the control element. It reconnects the original resistance in the torque motor circuit. This returns the control element to its normal voltage setting. If the voltage is still below normal, this will again close the control element and "inch" the rheostat a small amount. The vibration of the control element and auxiliary relay is repeated, the rheostat inching each time until the voltage is within the normal band.

It is necessary to slow down the rate of rheostat operation as normal voltage is approached so that the voltage does not raise above the correct value. The voltage does not stop rising when the rheostat stops. The increase in field current lags the rheostat movement in the highly inductive field circuit. Neither does the rheostat motor stop the instant the control element opens. Hence, the inching of the rheostat allows the voltage to settle at whatever higher value it will before the rheostat attempts to raise it further.

Operation of the voltage lowering circuits when generator load change causes a voltage rise, are similar to the above.

Operation of the Complete Regulator on a Severe Voltage

The high speed raising contactor closes, while at the same time the rheostat begins to move. The voltage builds up rapidly as the resistance has all been shorted out and when near normal, the control element and contactor vibrate to hold approximately correct average field current. This vibration was explained under operation of the high speed contactors. While the voltage is thus held up, the rheostat is moving towards the setting for holding correct field current. The vibration of the control element opens and closes its second contact for the high speed contactor, but not the first contact for the rheostat, since the spring of the first or rheostat contact has been fully depressed in the closing of the second or high speed contactor contact and does not open circuit as the high speed contactor contacts open and close. Normally as the rheostat approaches its new position after the high speed contactor has stopped vibrating, the first or rheostat contact will also vibrate.

When the rheostat is far enough to hold the voltage at or above the point below which the second contact closes, then the high speed contactor will remain open. From here on the rheostat will operate to restore voltage as previously described, just as though the voltage deviation had been only sufficient to operate the rheostat contacts.

Operation of the voltage lowering circuits on a large voltage rise are similar to the above.

Parallel Operation of Two Units

Stability is had by giving each voltage regulator a drooping characteristic with increasing lagging wattless load on its generator. This is much the same as operating prime mover governors in parallel with drooping characteristics as power load increases. Over-excitation on one unit and under excitation on the other

while creating unbalanced wattless loading or circulating currents, could still maintain normal bus voltage. Thus, without a compensating droop, no change in the regulator positions would take place to equalize currents.

The cross current compensator is a calibrated resistance in the torque motor circuit of the control element. Current transformers supply it and produce a voltage drop in it proportional to load. Current is taken from the proper phases so that when it is at unity power factor the drop does not affect the control element, but when the current is lagging, the 90 degree wattless component produces an aiding voltage drop and forces the torque motor to hold a lower bus voltage. Also, a leading load current will give the regulator a higher voltage setting which it will maintain. The result is that when the excitation of two units tend to swing apart, each regulator has its setting so changed that operations are set up which bring them together. The voltage will decrease slightly as lagging wattless load increases. The compensation must be set to produce as little drop in voltage from this lagging wattless current as possible, and at the same time have enough effect to stabilize the regulators.

The foregoing paragraphs describe briefly the operation of the new type "J" rocking contact rheostatic voltage regulator when applied to alternating current machines. There are many adaptations of this regulator to meet special conditions as well as its use for control of direct current generators.

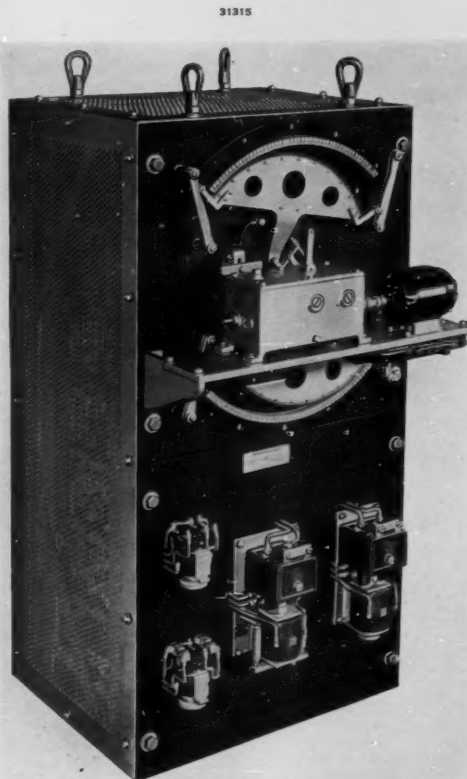
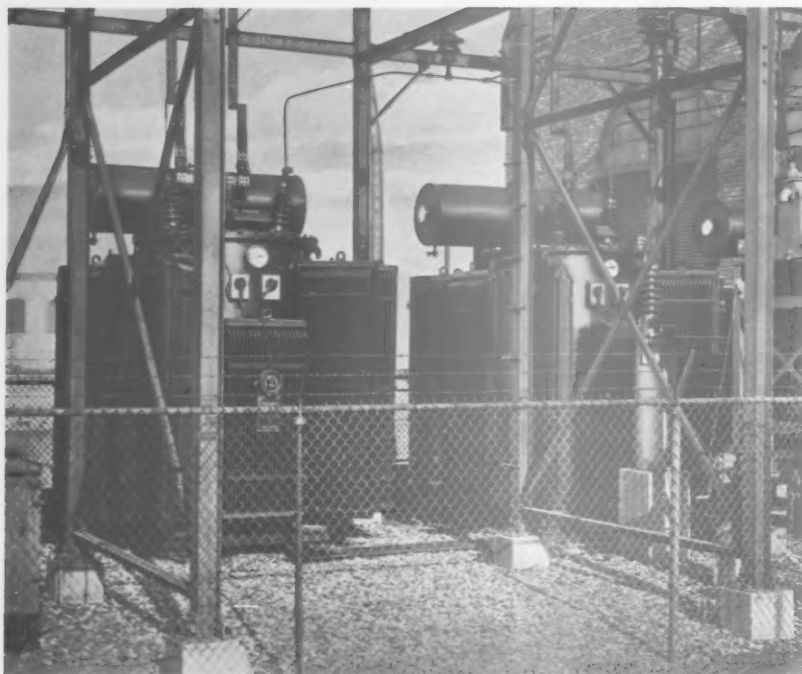


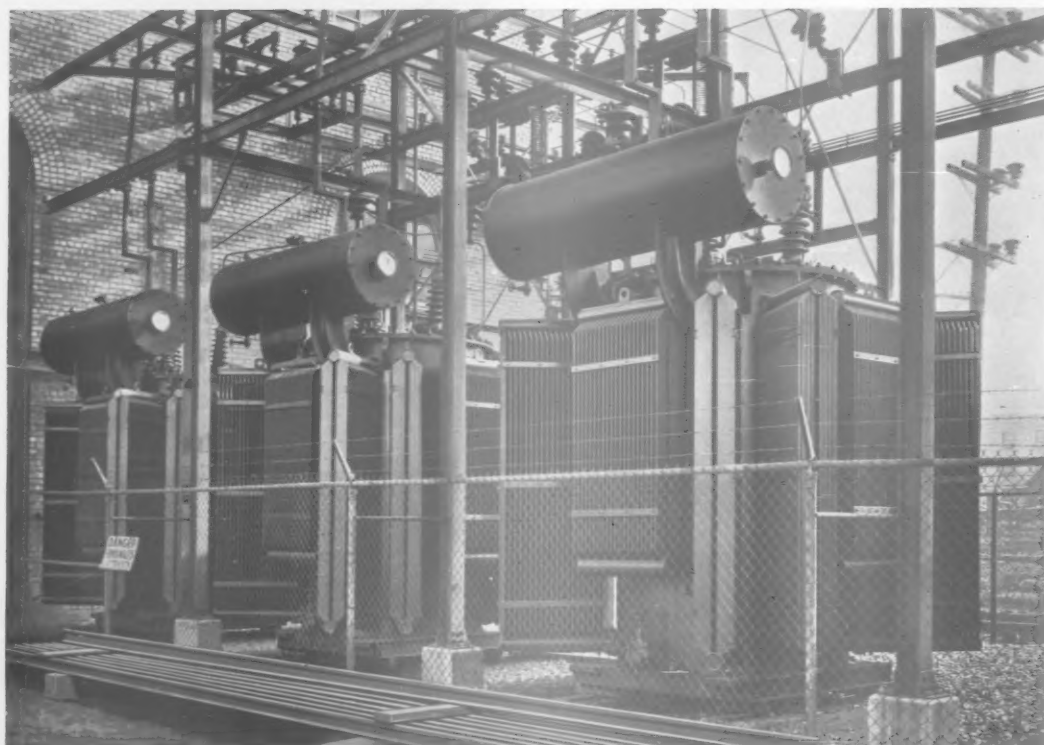
Fig. 2—Rocking Contact Rheostat and High Speed Contactors



31013

*Above and below—Three
6667-kva, single-phase,
OISCO Transformers.
High voltage 44,000 volts,
low voltage 2300 volts.*

31011



THREE AND FOUR WINDING TRANSFORMERS

W. C. SEALEY
Transformer Division
Allis-Chalmers Mfg. Co.

PART I—GENERAL THEORY

A TRANSFORMER consists essentially of two or more windings on the same iron core. Fig. 1 illustrates a two-winding transformer in which one winding is connected to the supply and the other to the load, the two windings carrying currents in opposite directions.

When the mechanical construction is examined, each winding by itself is seen to be a coil possessing inductance. When the coil carries current, a flux is set up in the iron core and in the air about it. A large part of the flux set up by one coil links the turns of the other coil, due to the fact that the two windings are placed close together as shown in Fig. 2. Because the flux of one coil cuts the turns of the other in this way, there is mutual inductance between the windings, and since the currents of the two windings are in opposite directions around the core, the effect of the mutual inductance is to reduce the effective inductance of the coils.

This circuit, consisting of the self inductance of the two coils with the mutual inductance between them, can be used for calculation of the voltage and current relations in the transformer. For use in power circuits, however, such an equivalent circuit is complicated to use, and the values are not easy to determine.

Neglecting magnetizing current, a much simpler equivalent circuit which is sufficiently accurate for power circuits, can be derived which contains no mutual inductance. As indicated in Fig. 3, this circuit contains self inductance and resistance only. In this and following diagrams Circuit No. 1 is shown as the supply. Any of the other windings can be used as the supply winding without change of constants.

For the sake of simplicity, the voltages, currents and impedances of such a circuit are usually expressed in per cent. Any values of current and voltage may be taken for the percentage base. The most usual one is the normal voltage of the windings and full load current, but any convenient base may be chosen.

If the current I_b and the voltage E_b are taken as the base, the base kva is $I_b E_b$. If the reactance voltage drop caused by the current I_b through the transformer

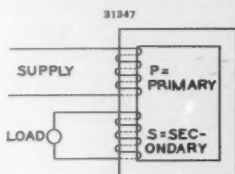


Fig. 1



Fig. 2

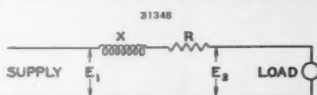


Fig. 3

A Description of the Most Useful Equivalent Circuits for Multiple Winding Transformers

of Figs. 1 and 2 is E_x volts, then the per cent reactance of the transformer is $\frac{E_x}{E_b} \times 100$. This is the per cent reactance referred to the base $I_b E_b$. If the base is changed, the per cent reactance will also change.

Similarly, if the resistance voltage drop through the winding due to the current I_b is E_r , the per cent resistance is equal to $\frac{E_r}{E_b} \times 100$. These voltages are measured

by short circuiting one winding and applying sufficient voltage on the other to cause the current I_b to flow. The component of this voltage 90° out of phase with the current I_b is the voltage E_x . The component in phase with the current I_b is the voltage E_r . The per cent resistance is also equal to 100 times the copper loss with the current I_b flowing divided by the base kva ($E_b \times I_b$).

Because of its simplicity, this equivalent circuit is the one most generally used for power transformers, although there are other possible circuits.

A three-winding transformer is in reality a two-winding transformer with a third winding added to it. If the third winding carries no current, it may be ignored in deriving the equivalent circuit.

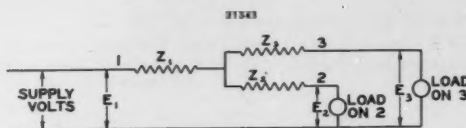


Fig. 4

It is obvious that each of the three coils of a three-winding transformer has self inductance. Being placed close together on the core, the three coils also have fluxes which link each other. The circuits of a three-winding transformer contain the three self inductances of the windings and the mutual inductances between them. However, as in the case of the two-winding transformer, there are other and simpler equivalent circuits which may be used. The circuit lending itself most readily to calculation and derivation of its values should be chosen. The one shown in Fig. 4, for example, is to be preferred because it is the simplest to use and its constants are the easiest to determine.

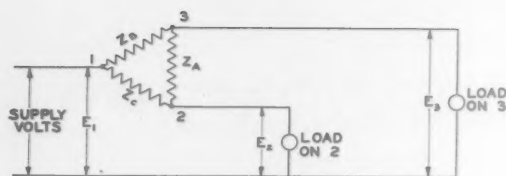


Fig. 5

31333

Fig. 5 shows an equally valid circuit but the derivation of its constants for any particular case is more laborious.

For the circuit of a given three-winding transformer, three impedance values are required for evaluating the constants. These values consist of the impedance of every winding to every other winding, with the third winding idle. If the windings are numbered 1, 2 and 3, the required impedances are:

- Winding 1 to winding 2 with winding 3 idle.
- Winding 1 to winding 3 with winding 2 idle.
- Winding 2 to winding 3 with winding 1 idle.

These values are measured or calculated from the dimensions of the transformer just the same as if it were a two-winding transformer.

In the equivalent circuit of Fig. 4, the impedance from winding 1 to winding 2 is equal to Z_1 plus Z_2 . Similarly, the impedance from winding 1 to winding 3 is equal to Z_1 plus Z_3 , and the impedance from winding 2 to winding 3 is equal to Z_2 plus Z_3 .

If these relations are put in the form of equations which are solved for Z_1 , Z_2 and Z_3 , the impedance values in the equivalent circuit for this particular three winding transformer are obtained.

The values of impedance measured between windings can be expressed in the form of complex quantities to represent the resistance and reactance components of the impedance, and the circuit constants can be evaluated by substituting in the equations. A simpler method is to use the equations twice, first considering only the resistance component of the impedances, and, second, only the reactance component. The two methods will give identical results.

After the values of impedance are obtained for the various links of the circuit, the equivalent circuit can be used to determine current and voltage relations in the circuit for various loading conditions or for short circuit conditions. The equations for the quantitative solution of the circuits are given in Part II.

For a three-winding transformer, the equivalent circuit shown in Fig. 4 is relatively simple to use, even

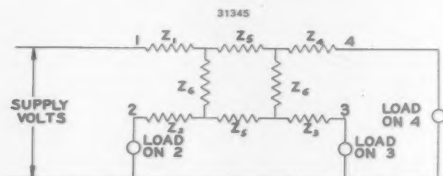


Fig. 6

for analytical calculations. For a four-winding transformer, the circuit diagram is considerably more complicated and correspondingly difficult to use. The one shown in Fig. 6 is probably the simplest to derive and the easiest to use. However, it is not the only circuit

which may be used. Other possible circuits for a four-winding transformer are shown in Fig. 7.

When a four-winding transformer is under consideration, it is advisable to treat it as a three-winding transformer if only three of the windings are to carry a load, unless, of course, the voltage relations for the fourth winding are also desired.

The values of impedance which are used to obtain the equivalent circuit of a four-winding transformer are:

- Impedance between winding 1 and 2 with windings 3 and 4 idle.
- Impedance between winding 1 and 3 with windings 2 and 4 idle.
- Impedance between winding 1 and 4 with windings 2 and 3 idle.
- Impedance between winding 2 and 3 with windings 1 and 4 idle.
- Impedance between winding 2 and 4 with windings 1 and 3 idle.
- Impedance between winding 3 and 4 with windings 1 and 2 idle.

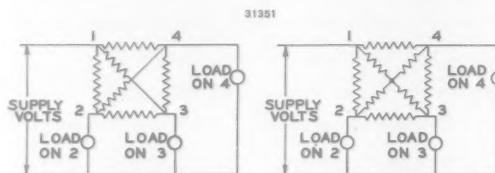


Fig. 7

Given these impedances and using the network of Fig. 6, equations can be set up for the impedance between lines in terms of the link impedances. After these equations have been solved for the link impedances, the equivalent circuit can be used to determine voltage and current relations under various conditions of loading.

In using the equivalent circuit of the four-winding transformer the principle of superposition can be used to advantage. In this method, the load current on each winding is considered separately as if the other windings were not loaded, and the current and the voltage relations in the circuit are determined separately for the load on each winding. The actual relations in any link under combined loading are obtained by vector addition of the currents and of the voltage drops in that link.

Where frequent solution of circuits involving four-winding transformers is required, a calculating board is of great help. This consists of adjustable impedances by means of which the equivalent circuit can be set up with links having impedances proportional to the calculated impedances of the equivalent circuit. If voltage is applied to the terminals corresponding to the supply circuit, ammeter, voltmeter and wattmeter readings can be taken to determine the voltage and current relations of the circuit. These values represent the voltage and current relations existing in the transformer.

So far, diagrams have been shown for only single-phase circuits. A three-phase circuit may be considered as a combination of three single-phase circuits. The impedance in each line of the three-phase circuit may be calculated on the basis of the voltage to neutral and normal line current. The resulting three-phase circuit can be used in the conventional way for the determination of voltage and current relations.

For balanced three-phase circuits, it is necessary to

solve only one of the single-phase circuits, since the solutions for the other two are plainly the same.

Sometimes when the constants are determined, the resistance will have a negative sign and the reactance will be capacitive. This is entirely possible and does not represent an unusual condition. Neither does it mean unusually high short circuit currents, since this link must always be in series with other windings with much larger values of positive resistance and inductive reactance.

PART II—GENERAL FORMULAE

For quantitative evaluation of the constants of the circuit of the 3-winding transformer shown in Fig. 4, the following equations are given:

If Z_{12} is the impedance between windings 1 and 2; Z_{13} the impedance between winding 1 and 3 and Z_{23} the impedance between windings 2 and 3 with the third winding open in each case:

- (1) $Z_{12} = Z_1 + Z_2$
- (2) $Z_{13} = Z_1 + Z_3$
- (3) $Z_{23} = Z_2 + Z_3$

Solving these equations for Z_1 , Z_2 and Z_3 ,

$$(4) \quad Z_1 = \frac{Z_{12} + Z_{13} - Z_{23}}{2}$$

$$(5) \quad Z_2 = \frac{Z_{12} + Z_{23} - Z_{13}}{2}$$

$$(6) \quad Z_3 = \frac{Z_{13} + Z_{23} - Z_{12}}{2}$$

These equations can be used for evaluating the constants of the circuit. An example of their use will be given in Part III.

For quantitative evaluation of the constants of the circuit of the 4-winding transformer shown in Fig. 6 the following equations are given:

Z_{12} is the impedance between windings 1 and 2 with the other windings idle. Similarly Z_{13} , Z_{14} , Z_{23} , Z_{24} and Z_{34} are the impedances with the windings not mentioned in the subscript idle.

From inspection of Fig. 6, the equations representing the impedances measured between the various windings with the other windings idle are:

$$Z_{12} = Z_1 + Z_2 + \frac{1}{\frac{1}{Z_5} + \frac{1}{2Z_5 + Z_6}}$$

$$Z_{13} = Z_1 + Z_3 + \frac{1}{\frac{1}{Z_5} + \frac{1}{Z_5 + Z_6}}$$

$$Z_{14} = Z_1 + Z_4 + \frac{1}{\frac{1}{Z_5} + \frac{1}{Z_5 + 2Z_6}}$$

$$Z_{23} = Z_2 + Z_3 + \frac{1}{\frac{1}{Z_5} + \frac{1}{Z_5 + 2Z_6}}$$

$$Z_{24} = Z_2 + Z_4 + \frac{1}{\frac{1}{Z_5} + \frac{1}{Z_5 + Z_6}}$$

$$Z_{34} = Z_3 + Z_4 + \frac{1}{\frac{1}{Z_5} + \frac{1}{2Z_5 + Z_6}}$$

Solving these equations simultaneously and letting:

$$A = Z_{13} + Z_{24} - Z_{12} - Z_{34}$$

$$B = Z_{13} + Z_{24} - Z_{14} - Z_{23}$$

there results:

$$Z_5 = A + \sqrt{AB}$$

$$Z_6 = B + \sqrt{AB}$$

and

$$Z_1 = \frac{1}{2} (Z_{13} + Z_{12} - Z_{23} - Z_6)$$

$$Z_2 = \frac{1}{2} (Z_{24} + Z_{23} - Z_{34} - Z_5)$$

$$Z_3 = \frac{1}{2} (Z_{13} - Z_{12} + Z_{23} - Z_5)$$

$$Z_4 = \frac{1}{2} (Z_{24} - Z_{23} + Z_{34} - Z_6)$$

When using the above equations for a particular transformer, in order that Z_5 and Z_6 may be represented by inductive reactance ($Z_{13} + Z_{24}$) must have a greater inductive reactance than ($Z_{13} + Z_{23}$) or ($Z_{12} + Z_{34}$). This is accomplished by properly assigning the numbers to the various windings. Each of these three sums is composed of two impedances, using each winding only once. This is evident because no number appears twice in the subscripts of a group.

An example of the use of these equations for a particular transformer is given in Part III.

PART III—EXAMPLES

These two examples show the use of the equations of Part II in detail considering the reactance only. (For some purposes the resistance of the circuit may be neglected when it is small compared to the reactance.) No steps are omitted in the solution, so it can be checked without difficulty.

Example No. 1—Three Winding Transformer

A three-winding transformer has a reactance from winding No. 1 to winding No. 2 of 10%. The reactance from winding No. 1 to winding No. 3 is 12%. The reactance from winding No. 2 to winding No. 3 is 8%.

Then:

$$Z_{12} = 10$$

$$Z_{13} = 12$$

$$Z_{23} = 8$$

From Part II for the three-winding transformer:

$$Z_1 = \frac{Z_{12} + Z_{13} - Z_{23}}{2} = \frac{10 + 12 - 8}{2} = 7\%$$

$$Z_2 = \frac{Z_{12} + Z_{23} - Z_{13}}{2} = \frac{10 + 8 - 12}{2} = 3\%$$

$$Z_3 = \frac{Z_{13} + Z_{23} - Z_{12}}{2} = \frac{12 + 8 - 10}{2} = 5\%$$

The equivalent circuit of this transformer is shown in Fig. 8. Any one of the three terminals can be used as the supply with the other two windings loaded.

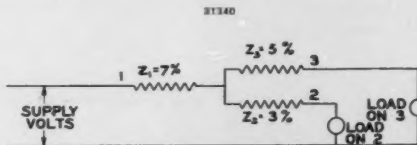


Fig. 8

Example No. 2—Four Winding Transformer

A four winding transformer has the following reactances:

- From winding No. 1 to winding No. 2—10%
- From winding No. 1 to winding No. 3—12%
- From winding No. 1 to winding No. 4—16%
- From winding No. 2 to winding No. 3—8%
- From winding No. 2 to winding No. 4—14%
- From winding No. 3 to winding No. 4—8%

Then:

$$\begin{aligned} Z_{12} &= 10 \\ Z_{13} &= 12 \\ Z_{14} &= 16 \\ Z_{23} &= 8 \\ Z_{24} &= 14 \\ Z_{34} &= 8 \end{aligned}$$

From Part II for the four winding transformer:

$$A = Z_{13} + Z_{24} - Z_{12} - Z_{34} = 12 + 14 - 10 - 8 = 8$$

$$B = Z_{13} + Z_{24} - Z_{14} - Z_{23} = 12 + 14 - 16 - 8 = 2$$

$$Z_5 = A + \sqrt{AB} = 8 + \sqrt{2 \times 8} = 8 + 4 = 12$$

$$Z_6 = B + \sqrt{AB} = 2 + \sqrt{2 \times 8} = 2 + 4 = 6$$

$$Z_1 = \frac{1}{2} (Z_{13} + Z_{12} - Z_{23} - Z_0) = \frac{1}{2} (12 + 10 - 8 - 6) = 4$$

$$Z_2 = \frac{1}{2} (Z_{24} + Z_{23} - Z_{34} - Z_0) = \frac{1}{2} (14 + 8 - 8 - 12) = 1$$

$$Z_3 = \frac{1}{2} (Z_{13} - Z_{12} + Z_{23} - Z_0) = \frac{1}{2} (12 - 10 + 8 - 12) = -1$$

$$Z_4 = \frac{1}{2} (Z_{24} - Z_{23} + Z_{34} - Z_0) = \frac{1}{2} (14 - 8 + 8 - 6) = 4$$

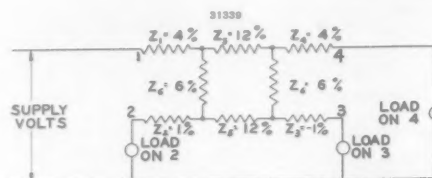
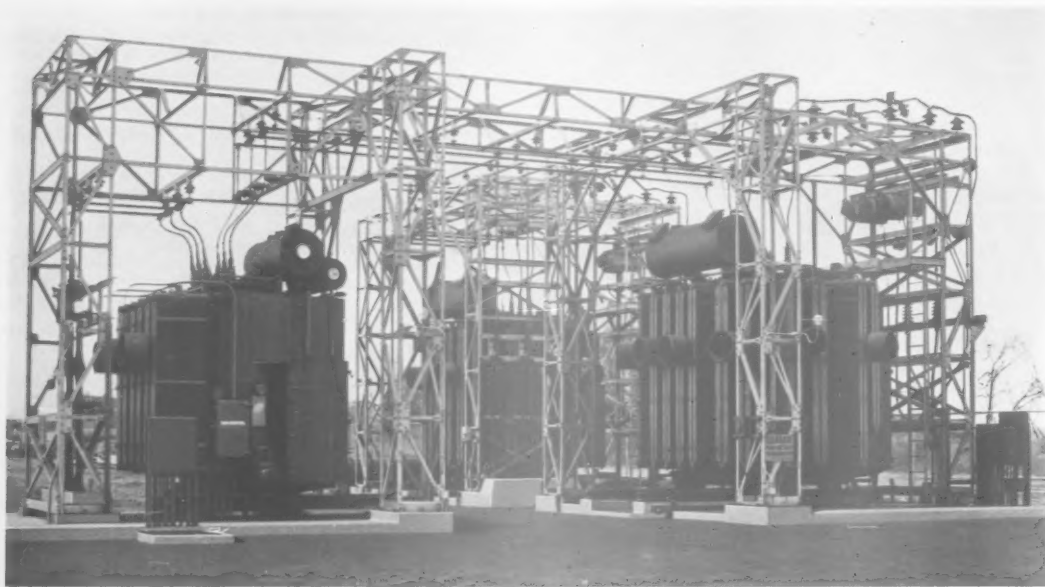


Fig. 9

The equivalent circuit of this transformer is shown in Fig. 9. Any of the four terminals (1-2-3 or 4) can be used as the supply with the other three windings loaded.

(This is the first of two articles on multiple winding transformers.)



4400-kva Phase Shifter
Type OISCTO-FA

20,000-kva Load Ratio and Phase
Angle Control, Type OISCTO-FA

20,000-kva Transformer, Type OISCTO-FA,
with Integral Load Tap Changer

AS *Unlike* AS PEAS IN A POD

● Peas in a pod may look exactly alike . . . in color, in size, in shape . . . but naturalists know that these seemingly identical peas have huge inherent differences—one may engender a sturdy race, another a race of weaklings.

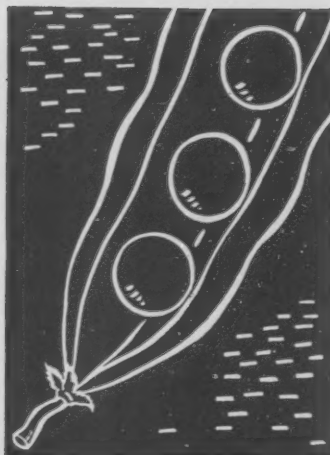
PEAS . . . and MOTORS! In both, the possibilities for inherent differences are great.

Motors can be built of light materials so that they will hold together and fulfill their electrical characteristics . . . but what about their mechanical durability?

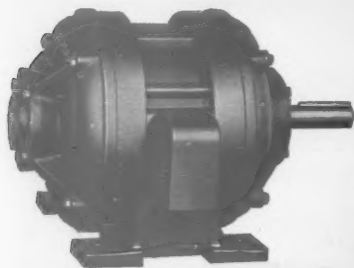
Allis-Chalmers Motors excel because they were distinctly designed and developed for severe industrial duty. They were not developed through our electrical department alone, but through our electrical department working closely in conjunction with all the highly specialized knowledge and experience of all the various departments of the Allis-Chalmers Mfg. Co., builders of the most diversified line of machinery on the American continent.

Allis-Chalmers Motors have been designed and built not only to deliver their electrical characteristics precisely, but to take a beating day after day and year after year and continue to deliver them faithfully. They are the sturdiest motors on the market—bar none.

Their great mechanical strength reduces maintenance costs to the minimum and extends their life beyond that of all less sturdily constructed motors, making them the most profitable motor buy on the market today.



The Allis-Chalmers Mfg. Co. builds standard motors of every type from 1 hp. up—also motors for special application



MOTOR DIVISION
ALLIS-CHALMERS

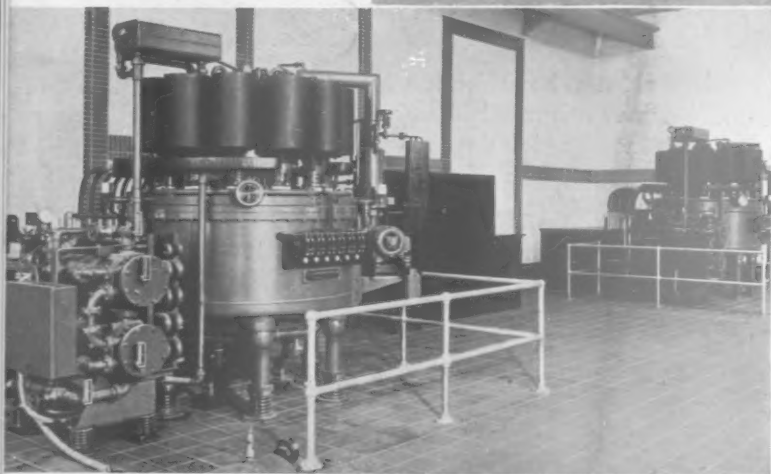
M I L W A U K E E W I S C O N S I N



(Right) View of New High Speed Transit Line on Delaware River Bridge.

(Below) Interior View of substation on Camden side of bridge showing two of four 2000kw, 630volt Allis-Chalmers Mercury Arc Rectifiers.

8000 KW OF
RECTIFIERS




TRAINS run swiftly, smoothly over this Delaware River Bridge new high speed transit line that forms an important connecting link between Philadelphia and Camden.

And to assure uninterrupted service, all equipment that has a part in supplying d-c power to that line is Allis-Chalmers — 8000 kw of Mercury Arc Rectifiers, 12,500 kva of Transformers, 26 Armored Switchgear Units.

ELECTRICAL DIVISION
ALLIS-CHALMERS



M I L W A U K E E W I S C O N S I N



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